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Greenland Halibut (Reinhardtius hippoglossoides of the Eastern Bering Sea and the Aleutian Islands Region: a Review

by

Miles S. Alton, Richard G. Bakkala, Gary E. Walters, and Peter T. Munro [1]

Northwest and Alaska Fisheries Center, National Marine Fisheries Service,
7600 Sand Point Way NE, BIN C15700, Building 4, Seattle, WA 98115

ABSTRACT

Greenland halibut is a commercially important flounder in both the North Atlantic and North Pacific Oceans. In the latter, its center of abundance resides in the eastern Bering Sea and along the Aleutian Islands chain where its population is managed as a stock unit. Harvest levels in this region of the North Pacific in the period 1970-81 were comparable to those in the northwest and northeast Atlantic with annual average catches of 53 thousand t. Since 1983, the catch from the eastern Bering Sea and Aleutian Islands has declined so that by 1986 only 9.8 thousand t were taken. The period of decline is associated with the phase-out of the foreign directed fisheries and the rise in domestic fisheries in the U.S. Fishery Conservation Zone. During the same period, the quota was reduced because of concern over continued poor recruitment.

Recruitment failure was manifested in (1), the sharp decline in the catch rate of young fish in annual research trawl surveys on the eastern Bering Sea Continental Shelf, and (2) an increasing proportion of older and larger fish in the commercial catch from the Continental Slope of both the eastern Bering Sea and Aleutian Islands. The cause of the decline in recruitment could not be clearly identified.

There is an apparent bathymetric change in the size and age of fish, with the younger animals occupying Continental Shelf depths and the older individuals residing at depths of the Continental Slope. Those animals on the shelf are exposed to colder temperatures than those on the slope where temperatures are relatively stable.

A hypothesis is proposed for describing the temporal and spatial paths by which the young animals reach the mature or spawning portion of the population.

SPECIAL SESSION ON DEEPWATER FISHES

INTRODUCTION

This review covers the history of harvest and management of Greenland halibut[2/] (Reinhardtius hippoglossoides) stock of the eastern Bering Sea and Aleutians and describes the characteristics of the fisheries and the temporal and spatial patterns of harvest and of catch per unit effort. It also traces changes that have occurred in the abundance and composition of the stock as inferred from both fisheries and research vessel survey data. A hypothesis is proposed for the eastern Bering Sea-Aleutian stock which describes the possible temporal and spatial pathways by which young fish recruit to the adult population.

1/ Northwest and Alaska Fisheries Center, National Marine Fisheries Service, 7600 Sand Point Way NE, BIN C15700, Building 4, Seattle, WA 98115.

2/ Also called Greenland turbot, a market name used on the west coast of the U.S. and in Alaska.

In the North Pacific, Greenland turbot has its center of abundance in the eastern Bering Sea followed by the Aleutian Islands region. It is also of some importance, in terms of abundance, in the Okhotsk Sea and the northern Kurile Islands (Shuntov, 1965). The most southward occurrence of the species is the Sea of Japan in Asian waters and off the coast of northern Baja California in North American waters. Within the Bering Sea it occurs throughout the region in shelf and Continental Slope waters.

The Pacific Ocean form of Greenland halibut is closely related to the North Atlantic form, morphometrically and meristically (Hubbs and Wilimovsky, 1964). From biochemical genetic studies, Fairbairn (1981) concluded that divergence has occurred between the Bering Sea population and that of the Northwest Atlantic at the subspecific level. Using Fairbairn's data, Grant (1987) recomputed genetic distance by including findings for all loci and could find no evidence that divergence had proceeded to the subspecific level. This suggested to him that gene flow between the Bering Sea fish and those of the northwest Atlantic was either continuing or had taken place in recent times.

Harvest levels of Greenland halibut in the eastern Bering Sea and Aleutian Islands in the period 1970-81 were comparable to those in the northwest and northeast Atlantic with annual average catches of 53 thousand t. Cumulative catches in the period 1970-81 were 679,000 t in the northeast Atlantic, 556,000 t in the northwest Atlantic and 636,000 t in the eastern Bering Sea-Aleutian Islands (Table 1). Peak annual catches occurred in the northeast Atlantic (98,000 t) and Bering Sea (78,000 t) in the early 1970's and in the northwest Atlantic (63,000 t) in the late 1970's.

We believe that Greenland halibut of the eastern Bering Sea and Aleutians are of one stock because of evidence that the source of recruitment to the populations of both regions comes from the eastern Bering Sea shelf. Those Bering Sea fish in U.S.S.R. waters (e.g. Gulf of Anadyr) are more than likely an extension of the eastern Bering Sea population. We have very little information on the distribution and abundance of fish occurring in the U.S.S.R. zone of the Bering Sea.

PHYSICAL AND BIOLOGICAL SETTING

The eastern Bering Sea is one of the most biologically productive regions in the world's oceans. It contains some of the largest marine mammal, fish, and crab populations in the world. Almost all major fish and shellfish resources in the eastern Bering Sea are presently under commercial exploitation. Since 1970 the annual removals of demersal fishery resources by man have exceeded 1.6 million mt and in the peak year of 1972 reached 2.2 million mt.

Greenland halibut is one of several abundant fishery resources of this region that include pollock (*Theragra chalcogramma*), Pacific cod (*Gadus macrocephalus*), and soles and flounders (Bakkala and Wakabayashi, 1985). It is in the slope area where Greenland halibut has its highest biomass along with that of the grenadiers. In the Aleutians, Greenland halibut is much less important than in the Bering Sea and ranks in abundance below that of many other forms, particularly grenadiers at lower slope depths (Wilderbuer et al., 1985). For the combined eastern Bering Sea and Aleutian Islands region the exploitable biomass of Greenland halibut was estimated in 1986 to be 400 to 450 thousand t (Bakkala et al., 1987).

The eastern Bering Sea has several prominent features related to the environment of Greenland halibut. It has a very broad shelf where the young halibut grow and develop (Fig. 1). The shelf is a harsh environment being subject to extremes of cold conditions. Sea surface ice covers much of the shelf during the winter months and reaches its greatest southward extension in March and April. The southward extension varies from year to year depending on climatic conditions and may reach the vicinity of the Pribilof Islands or beyond in some years such as 1976. By July, the shelf is ice-free. A persistent feature of the shelf is a layer of residual cold bottom water of 0°C and less from winter that occurs at midshelf depths and extends from the Gulf of Anadyr towards the southeastern part of the shelf. Its southeastward extension during the summer months varies each year depending on the severity of conditions in the previous winter. This cold bottom layer may have a bearing on the shelf distribution of the very young Greenland halibut.

In the slope area of both the eastern Bering Sea and Aleutian Islands seasonal extremes in temperature are absent. Bottom water temperatures have a narrow range of 3 to 5°C at depths (400-1000 m) where the adult Greenland halibut appear to be most dense. Most of the bottom habitat of the Aleutian Islands lie at slope depths, since there is very little shelf area in this region.

For a detailed account of various physical and biological aspects of the eastern Bering Sea environment see Hood (1986) and Hood and Calder (1981).

INFORMATION SOURCES

In preparation of this review we have examined literature sources and the findings from the analysis of fisheries and research vessel surveys.

Fisheries

Major emphasis is placed on the catch and effort data from those fisheries (namely Japanese) which targeted on Greenland halibut or took large amounts of Greenland halibut as bycatch. Targeted fisheries include the Landbased Dragnet Fishery, the North Pacific Trawl Fishery (involving small trawlers), and the vessels using longline gear. The nontargeted fishery was comprised of mothership operations where catcher vessels landed their catches aboard the processing or mothership vessel.

The Landbased Dragnet Fishery operated west of 170°W longitude in the Bering Sea and Aleutians region because of licensing restrictions imposed in Japan. Vessels in this fishery could not trans-ship their catch to Japan, but had to offload their processed catch in Japan. None of the other fisheries had these restrictions.

We have relied solely on catch and effort estimates derived from the U.S. Observer Program database to examine for patterns in catch and CPUE by area, season, and depth. The program, which began in 1977, places observers aboard foreign fishing vessels for the collection of catch and effort data, catch composition, and biological information on targeted species. The resulting catch data is called "best blend", since the estimating procedure uses both observer estimates of catch and reported catch by foreign vessels (Nelson et al., 1981). Emphasis is placed on the findings for the eastern Bering Sea because of the greater completeness of sampling coverage by time, depth, and area. For the Aleutians, the desultory nature of the fishing by time and area and the paucity of observer coverage prevents an adequate identification of area-time-depth catch patterns for this region.

Only biological data from the fisheries that were collected by U.S. observers aboard Japanese vessels were used. These data consist for the most part of fish lengths by sex for the years 1978-85. Otoliths were collected during these years but because of higher priorities placed on the Ageing Unit of the Northwest and Alaska Fisheries Center, these otoliths have not been read. Some data are available on the weight of individual fish related to length and sex.

Standard procedures established by the U.S. Observer Program (Nelson et al., 1981) were followed in the collection of length data. When Greenland halibut was a vessel's targeted species, the observers obtained a random sample of some 150 fish from each day's catch of this species. The total length of each fish and its sex were determined. In addition to random samples a sample stratified by length groups (5 fish of each sex for each 1-cm interval) was collected in which each fish was weighed to the nearest hundredth of a kilogram and its otolith removed for later age determination. Data from these stratified-by-length collections provided the means of converting catch in weight to catch in numbers by using length-weight relationships.

Since individual trawl catches were sampled in the targeted fisheries for length information, the observer was able to record important ancillary information so that length data could be related to catch magnitude, fishing effort, area, and depth. Whenever length information was combined into large area-time-depth cells, lengths from individual hauls were weighted by the catch of these hauls and then expanded to the total catch in the cell.

The majority of length data came from the catch of small freezer trawlers attached to either the Landbased Dragnet Fishery or the North Pacific Trawl

Fishery. The U.S. Observer database does not distinguish between these fisheries, but places vessels from both fisheries into the standard category of small freezer trawlers. Length data were also available from the Japanese longline and mothership fisheries.

Through trial and error, an area-season-depth stratification was constructed for the eastern Bering Sea, based on similarities and differences in length compositions of fish sampled from small freezer trawlers. The stratification that best described the changes in length composition was one based on three areas of the eastern Bering Sea Continental Slope (Fig. 2), and three depths (184-450 m, 451-730 m, and greater than 730 m), and 3-month intervals. For the Aleutians, length data were examined by the same depth intervals as above but by year rather than by quarter because of the limited seasonal data from the region.

Research Survey Data

In examining the temporal and geographic features of the distribution and abundance of Greenland halibut, we have used data gathered from extensive research trawl surveys of the eastern Bering Sea and Aleutians. Although annual trawl surveys of crab and bottomfish have taken place beginning as early as 1971, the first survey to adequately cover much of the eastern Bering Sea shelf occurred in 1975. This extensive survey was done by the NWAFC in response to the need for baseline information to evaluate the potential effects of oil exploration and development on the fishery resources of the region (Pereyra et al. 1976[3/]). Surveys of much lesser scope occurred in 1976, 1977, and 1978. Another extensive survey took place in 1979, but this was a joint effort by the Northwest and Alaska Fisheries Center (NWAFC) and the Fishery Agency of Japan (Bakkala et al., 1985) in which both the shelf and slope areas of the eastern Bering Sea were sampled. Following a triennial schedule Japanese and U.S. researchers conducted similar surveys of the shelf and slope in 1982 and 1985. In intermediate years (1980, 1981, 1983, 1984), surveys of the shelf were not as extensive in area and little if any effort was applied to the slope area. We have treated the results of the Japanese survey of the slope separate from that of the shelf area. Thus we have three years of slope survey data (1979, 1982, and 1985) and eight years of shelf survey data (1975, 1979-85).

Extensive trawl surveys of the Aleutians, which covered the areas both north and south of the Aleutian chain, began in 1980 and followed a triennial schedule, so that a second survey was conducted in the Aleutians in 1983 and a third in 1986. These surveys have also been a joint effort by the U.S. and Japan. Because of the relatively small shelf area in the Aleutians, most of the survey effort took place at depths greater than 183 m (Wilderbuer et al. 1985).

Trawling locations were preselected for the eastern Bering Sea and Aleutian surveys so as to cover both depth and area. The locations are given for the eastern Bering Sea by Pereyra et al. (1976[3/]), Wakabayashi et al. (1985), Umeda and Bakkala (1983), Sample et al. (1985), Bakkala and Wakabayashi (1985), Hirschberger (1985) and Halliday and Umeda (1986) and for the Aleutians by Wilderbuer et al. 1985. Haul duration was 0.5 hours for U.S. vessels and 1.0 hours for Japanese vessels.

Commercial-type fishing trawls were used. Those fished from U.S. vessels had a small mesh web (32 mm stretched mesh) lining the codend so that small animals such as juvenile fish could be retained. Japanese trawls had no liners but had triple layers of 90-100 mm stretched mesh in the codend. All trawls used in the Aleutians and in the slope area of the eastern Bering Sea were equipped with roller gear to reduce damage and hang-ups on the seabottom. Roller gear was not used during shelf surveys in the eastern Bering Sea.

Survey sampling methods are described by Wakabayashi et al. (1985). In general, total catches of less than about 1,150 kg were completely sorted by species and then weighed and counted. Catches over 1,150 kg were subsampled before sorting. Random samples of Greenland halibut were separated by sex and measured to the nearest cm. Otoliths were removed for later ageing from at least 5 fish of each sex per centimeter length interval during the survey.

3/ Pereyra, W. T., J. E. Reeves, and R. G. Bakkala. 1976. Demersal fish and shellfish resources of the eastern Bering Sea in the baseline year 1975. Processed Rep., 619 p. Northwest and Alaska Fisheries Center, National Marine Fisheries Service, NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

U.S. age samples through 1982 were read by NWAFC age readers. Due to reservations about methodology and results from these readings, we did not use this data. Samples collected since 1982 have not been read due to higher priorities for other species. However, age and related length data provided by the Fisheries Agency of Japan were used (1) as an age-length key to convert length data collected during NWAFC's 1979 survey to age and (2) to approximate the age of young fish during NWAFC's surveys of the eastern Bering Sea shelf in 1975 and 1980 through 1985. Japanese age data were based on otoliths collected by a Japanese research vessel operating in the shelf and slope region of the eastern Bering Sea in 1979. The approximation of the age of young fish was possible because of the high growth rate of juvenile Greenland halibut, which results in very little overlap in the length ranges of successive ages of young fish.

FISHERIES AND MANAGEMENT

Historical Account of Fisheries

Fisheries from Japan and U.S.S.R. were the first to harvest substantial amounts of bottomfish from the eastern Bering Sea and Aleutians. Japanese trawl fisheries operated in the eastern Bering Sea as early as the 1930's, but these fisheries were interrupted because of World War II and postwar restrictions. When Japan's fisheries resumed operations in the eastern Bering Sea during 1954, they expanded rapidly in geographic and species coverage as well as in level of harvest, diversifying into a number of distinct fisheries. By 1960, the total catch of bottomfish by Japanese fisheries reached some 449 thousand t, of which 36.8 thousand t were identified as "turbot" (Greenland halibut and arrowtooth flounder-Atheresthes stomias). This was the first year that Japan had reported "turbot" as a separate category. As a member of the International North Pacific Fisheries Commission (INPFC), Japan began in 1964 to provide catch and effort data for its fisheries operating in U.S. contiguous waters. The catch of "turbot" was not reported by species until 1977. However, Wakabayashi and Bakkala[4/] (1978) estimated the Japanese "turbot" catch by species for the years 1970-1976.

U.S.S.R. fishing fleets entered the eastern Bering Sea in 1959 and like the Japanese fisheries subsequently grew in scope. The reports of the Food and Agricultural Organization of the United Nations began to include the Soviet catch statistics in 1965. The Soviet catch was given by a very broad geographical area that encompassed the eastern Aleutian Islands, the eastern Bering Sea, and the Gulf of Anadyr. Beginning in 1972, the U.S.S.R. provided statistics on their fisheries in U.S. offshore waters under terms of bilateral agreements. These statistics were reported by species (including "turbot") and by broad INPFC statistical areas.

With implementation of the Magnuson Fisheries Conservation and Management Act (MFCMA) in 1977, all nations were required annually to report catch and effort of their fisheries that operated in the fishery conservation zone (FCZ) of the northeastern Pacific Ocean and Bering Sea according to INPFC standards. In the same year (1977), the Observer Program instituted procedures for obtaining an independent estimate of the foreign catch (best blend) in the FCZ.

The fisheries statistics for Greenland halibut can thus be placed into three reporting periods: The first, from 1960-69 gives an incomplete picture of the actual removals and does not provide catches of Greenland halibut consistently. The second, from 1970-76 (Table 2), is one in which the catch estimate for Greenland halibut is given but by statistical areas that differ among nations. The third, beginning in 1977 (Table 2), is one in which all nations follow the same reporting format and the U.S. Observer Program provides catch estimates (best blend) independent of that given by the reporting nations.

The period from 1970 to 1976 saw the decline in the U.S.S.R. catch of Greenland halibut and the rise of the Japanese catch (Table 2). The years from 1972 through 1976 were exceptionally productive when the average annual catch was some 70 thousand t and the maximum annual catch was 78.4 thousand t.

4/ Wakabayashi, K. and R. Bakkala. 1978. Estimated catches of flounders by species in the Bering Sea updated through 1976. Unpubl. Manuscr., 14 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Seattle, WA 98112.

Average annual removals from the Aleutian Islands during this productive period were only 7.1 thousand t.

After declining in 1977 the catch rose in 1978 and leveled off to between 47.5 and 57.3 thousand t for the years 1979 through 1983. Since 1983 the catch has declined so that by 1986 only 9.8 thousand t were taken. The drop in catch cannot be explained because of quota restrictions. Other factors, such as the phasing out of the Japanese Landbased Dragnet fisheries which targeted on Greenland halibut and restrictions on the bycatch of sablefish (Anoplopoma fimbria), may have brought about the reduced catch, particularly in 1985 and 1986. Sablefish can be an important bycatch when targeting on Greenland halibut, particularly at depths greater than 450 m.

Specific quotas for Greenland halibut were not set until 1986. Most of the 1987 quota of 20,000 t was allocated to U.S. directed fisheries with only a minor amount (1,750 t) given to foreign fisheries. There is no estimate at this time of the 1987 catch.

Japanese Fisheries

Japanese fisheries have accounted for the majority of the Greenland halibut catch from both the eastern Bering Sea and Aleutians until 1986. Among these fisheries, the Landbased Dragnet trawlers, the small trawlers attached to the North Pacific Trawl Fisheries (hereafter, simply called N. Pacific small trawlers), the surimi mothership fishery, and the longline fishery were the most important in terms of harvest magnitude and/or targeting on Greenland halibut (Table 3). The U.S. Observer Program did not distinguish between the Landbased Dragnet Fishery catch and that of the N. Pacific small trawlers. Instead, it provided an estimate for both fisheries (since 1977) under the designation "Japanese small freezer trawlers" (Table 3). We could not determine the Greenland halibut catch prior to 1977 by fisheries. Between 1977 and 1985, the annual catch of Greenland halibut in the eastern Bering Sea by the small freezer trawlers peaked at 41.2 thousand t in 1981 and sharply declined after 1983 to 14.2 thousand t in 1985 (Table 3). For the Aleutian Islands region, the catch by small freezer trawlers during the same time period was quite variable being as high as 8.9 thousand t in 1979 and as low as 1.6 thousand t in 1984. After 1984, there was no fishing by those vessels in the Aleutians. Small freezer trawlers fished mainly at bottom depths of the slope in both the eastern Bering Sea and Aleutians.

The mothership fishery operated only in the eastern Bering Sea and mainly on the Continental Shelf. Although there was no known targeting on Greenland halibut by this fishery, the incidental catch of this species was as high as 11.9 thousand t in 1978 (Table 3). The catch dropped to 9.8 thousand t in 1979 and 1980 and then rapidly declined in subsequent years so that by 1985 less than a thousand t were taken. The estimated number of Greenland halibut taken annually by the mothership fisheries during the years of high catches (1978-1980) ranged from 36.6 to 49.6 million.

In contrast to the mothership fishery, the Japanese longline fishery operated mainly in the slope region targeting on Greenland halibut in both the eastern Bering Sea and the Aleutians. Its catch in the eastern Bering Sea was consistently higher than that in the Aleutians (Table 3).

Relative importance of Greenland halibut in the Japanese fisheries: The importance of Greenland halibut relative to other species in the fisheries of the eastern Bering Sea and Aleutians increased with increasing bottom depth. On the shelf, the proportion of Greenland halibut in the catch was insignificant in comparison to that of the targeted species such as pollock, cod, and the various species of sole. In the Japanese mothership fishery, the incidence of Greenland halibut was slightly more than 2% in 1978, but declined to less than 0.3% (1984 and 1985). Catches by the Japanese small freezer trawlers and longline vessels were inconsequential at depths less than 183 m in both the eastern Bering Sea and Aleutians. In the slope region of the eastern Bering Sea, however, the importance of this species in the catch of small freezer trawlers sharply increased with depth, so that at depths exceeding 450 m it was the predominant species caught (Fig. 3). This was not the situation in the slope region of the Aleutians (Fig. 3), where pollock predominated in the catch of small freezer trawlers from upper slope depths (183-450 m), and grenadiers (rattails) comprised most of the catch from lower slope depths (>450 m).

For the Japanese longline fishery which took most of its catch from the eastern Bering Sea, the proportion of Greenland halibut in the total catch increased with depth so that at depths greater than 450 m it was the dominant species, followed by sablefish and rattails. However, the importance of Greenland halibut relative to sablefish in the longline fishery had declined significantly in 1984.

In the eastern Bering Sea, Japanese small freezer trawlers consistently took a greater tonnage of Greenland halibut from the Northern Slope area than from either the Central or Southern Slope area (Fig. 4). In turn, the removals from the Central Slope area tended to be greater than from the Southern Slope area.

When the catch of Greenland halibut by the small freezer trawlers is examined in terms of numbers of fish, the importance of the northern slope area becomes even more pronounced because of the smaller weight of individual Greenland halibut in the northern slope relative to the other slope areas (Fig. 5). In 1978, the estimated number of fish taken by these trawlers from the northern slope was in excess of 20 million, and the average annual removals for the years 1978-82 were about 17 million fish. In contrast, the average annual removals for the same period for the central slope were about 5 million fish and for the southern slope about 2 million fish.

In the northern and central slopes, most of the catch came from shallow (184-450 m) and intermediate (451-730 m) bottom depths. For the southern slope, the catches tended to be more evenly distributed among the three depth zones.

The Japanese surimi mothership fishery was active mainly during the summer and early fall months and operated for the most part on the Continental Shelf. Since 1980, there has been a marked decline in the magnitude of the catch from the northern part of the shelf (Fig. 6). By 1984, very little Greenland halibut was taken anywhere on the shelf.

The Japanese longline fishery operated mainly in the Central and Southern Slope region. Its main harvest of Greenland halibut and highest catch rates came from depths greater than 450 m.

In the Aleutians, Greenland halibut was also taken mainly at depths greater than 450 m by both the small freezer trawlers and longliners. Since the catch of Greenland halibut in this region has not been of much significance, we have not given any breakdown of the annual catch by area.

Length composition: There were marked differences among the Japanese fisheries in terms of the length of fish captured (Fig. 7). On the Continental Shelf of the eastern Bering Sea where the motherships operated, the catcher vessels took only small, immature fish. The larger juveniles and older fish tended to occur in the slope region, where they were subjected to harvest by the Japanese small freezer trawlers and longline vessels. The small freezer trawlers captured a broader size range of fish than the longline vessels in the same region of the slope. The latter vessel type took only the large fish, which are predominantly females. This selectivity difference between the longline vessels and small freezer trawlers occurred also in the Aleutians.

Management of Eastern Bering Sea - Aleutian Stock

Meaningful regulation of the Greenland halibut fishery was not established in the eastern Bering Sea until after implementation in 1977 of the Magnuson Fisheries Conservation and Management Act (MFCMA) of 1976. Some time-area restrictions and catch quotas were established prior to 1977 through the International North Pacific Fisheries Commission (INPFC) and bilateral agreements involving the United States and nations harvesting groundfish in the eastern Bering Sea and Aleutians. However, the catch quotas applied to broad groups of species, such as all flatfish or all species other than walleye pollock (*Theragra chalcogramma*), and these restrictions probably had little influence on any target fisheries for Greenland halibut.

Following implementation of the MFCMA, Greenland halibut of the eastern Bering Sea and Aleutians were managed as part of a group of species for which an annual allowable catch or optimum yield (OY)[5/] was set. Greenland halibut was included in a group designated as "other flounders" for the years 1977 to 1979. Other members of this group were arrowtooth flounder, rock sole (Lepidopsetta bilineata), flathead sole (Hippoglossoides elassodon), and other miscellaneous flatfish species. OY for this "other flounder" group was 100,000 t in 1977 and 159,000 t for the years 1978 and 1979. Because of the similarities in their life histories and distribution, Greenland halibut and arrowtooth flounder were placed in a separate management unit called "turbot" beginning in 1981. The OY of the "turbot" group was 90,000 t for the years 1980 to 1983, then reduced to 59,610 t in 1984 and further reduced to 42,000 t in 1985 because of indications of recruitment decline in Greenland halibut. Since this decline was accompanied by increases in the abundance of arrowtooth flounder, each species began to be managed as a separate unit in 1986. The OY for Greenland halibut was set at 28,050 in 1986 and reduced to 20,000 t in 1987 because of continued poor recruitment.

BIOLOGY, DISTRIBUTION, AND ABUNDANCE

Reproduction and Early Life History

There is very little detailed information on the relationship of maturity with sex, size, and age of Greenland halibut of the eastern Bering Sea and Aleutians. D'yakov (1982) mentions that maturity is reached at ages 5 through 10 and at sizes of 50 to 80 cm, but it is unclear as to whether he is referring specifically to Bering Sea fish or to fish from other areas. He does provide fecundity information on specimens collected during September to November in three areas of the Bering Sea - a northwestern area off Cape Olyutorski to 180° longitude, a northern area from 180° to 174°W longitude, and a southeastern area between 174° and 166°W. The southeastern Bering Sea and part of the northern area overlap the area considered in this review.

His studies show that absolute fecundity is more closely correlated with the weight of individual fish than with length, and that there are some notable regional differences in fecundity as well as with oocyte size. For a given individual weight, the Greenland halibut of the southeastern Bering Sea were more fecund than those fish examined from other regions. Oocyte size was significantly larger in fish from the southeastern and northern areas than in fish from the northwestern area. Considering specimens from all regions, fecundity ranged from 25 thousand eggs in 60-65 cm fish (about 2.5 kg in weight) to 145 thousand eggs in 96-100 cm fish (about 7 kg in weight).

Several Soviet investigations (Pertseva-Ostrumova 1961; Musienko 1970; Shuntov 1970; Bulatov 1983) have indicated a spawning period in the Bering Sea that begins as early as September and ends as late as March, Shuntov (1970) and Bulatov (1983) indicate that the slope off Unimak Pass is an important spawning area, whereas others (Musienko 1970; Pertseva-Ostrumova 1961) refer to a more northern location in the Bering Sea from off St. Matthew Island to the Gulf of Anadyr. It is more likely that spawning occurs in various slope areas throughout the Bering Sea and the Aleutian Islands, but the greatest amount of spawning may occur in the slope area between Unimak Pass and the Pribilof Islands. This is tentatively assumed based on the high density and frequency of occurrence of Greenland halibut larvae encountered in waters above the slope and outer shelf of this area during ichthyoplankton surveys (Waldron 1981) and indications of high densities of large fish in the southern slope of the eastern Bering Sea from both research trawl surveys and from the analysis of fisheries data (see Abundance section).

The eggs and early larval stages are bathypelagic and the later larval stages epipelagic (Bulatov 1983; Musienko 1970). The findings of eggs have been a rare event. A total of only 11 eggs have been reported for the eastern Bering Sea and all were taken during U.S.S.R. ichthyoplankton surveys (Bulatov 1983). The eggs were collected in February and March and from the vicinity of the slope between Unimak Pass and west of the Pribilof Islands by means of vertically hauled plankton nets.

5/ Optimum yield refers to the annual catch, which will provide the greatest overall benefit to the U.S., and which is prescribed on the basis of sustainable yield as modified by any relevant economic, social, or ecological factors. For Greenland halibut, OY is set by the North Pacific Management Council.

During the same U.S.S.R. surveys, the larvae were first encountered in early May and exclusively in vertical net hauls. By June most of the larvae were being caught in waters over the outer shelf of the southeastern Bering Sea. Average length of larvae measured was 33 mm. Two larvae (also 33 mm in length) were captured later in July some 200 miles north of the Pribilof Islands.

Bulatov's (1983) findings correspond to those of Waldron (1981) who found larvae during spring and summer months at surface and mid-depths in the same general region of the eastern Bering Sea. However, Waldron (1980) found a considerable spread of occurrences in both shelf and off-shelf waters and in waters north of the Pribilof Islands and north of the western Aleutian Islands (Fig. 8), but the densest encounters were in the vicinity of the slope and outer shelf of the southeastern Bering Sea between Unalaska Island and the Pribilof Islands. His findings were based on ten cruises that occurred from 1955 to 1978. Larvae ranged in size from 16 to 22 mm in April and May (Waldron and Vinter)[6/].

Settling of some young fish on the sea bottom occurs at least as early as July and August on the sea bottom of the eastern Bering Sea shelf, since 0-age fish have been captured in trawl surveys during these months. Kajimura (1984) reported the finding of some 500 young fish in the stomach of a northern fur seal (Callorhinus ursinus) which had been captured north of the Pribilof Islands in shelf waters in August. These fish were 45-60 mm in length and perhaps approaching the settling stage. It is assumed that they were consumed at depths off the bottom since fur seals normally feed on nektonic animals.

It is not possible to say where most of the young fish settle or whether there is a concentrating of recently settled fish. Their occurrences in NWAFC summer trawl surveys are rare. They only become available to the survey in large number some 7 to 11 months later at age-1 assuming that most fish settle to the bottom during the fall. It cannot be assumed that the locations of the densest age-1 fish on the shelf are those areas where the young fish had settled the previous fall. The young fish during its first months on the sea bottom may be greatly dispersed but eventually become aggregated in certain areas because of preferred habitats (e.g. specific temperatures, sediment type and prey) and perhaps attraction for its own kind.

In summary, our knowledge of the reproduction and early life stages of Greenland halibut in the eastern Bering Sea and Aleutian Islands region is fragmentary, but it does suggest that the slope area that lies north of Unimak Island as well as Unalaska Island (Fig. 1) may be an important spawning location during the late fall and early winter months. The larvae are present at least as early as April and May at sizes of 16 to 33 mm. There is some settling of the young fish on the bottom by July and August. It is presumed that most fish settle to the bottom during the fall.

Distribution of Age 1 and Older Fish

In the eastern Bering Sea, the size and age of Greenland halibut increases with increasing depth, with the younger animals occupying Continental Shelf depths and the older animals residing at slope depths. This has been reported by Shuntov (1970) from USSR fishery investigations in this region and is depicted in Fig. 9 from the results of a U.S.-Japan cooperative trawl survey in 1979. The fish encountered on the shelf are mostly of ages 1 through 4, which suggests that most fish of a cohort have entered the slope area by age 5 (Table 4).

Young Greenland halibut tend to be most available to the trawl at mid-and-outer shelf bottom depths north of the latitude of the Pribilof Islands. This region of the shelf has a bottom type of mixed sand and mud where several of the abundant members of the bottom fauna are species that have an Arctic-boreal distribution in both the North Pacific and North Atlantic. Examples of such species are the brittlestar, Ophiura sarsi, and the polychaete, Maldane sarsi, as reported by Neiman (1963), the cumacean, Eudorellopsis integra (see Barysheva 1964) and the commercially important snow crab, Chionoecetes opilio, and shrimp, Pandalus borealis. Both Greenland halibut

6/ Waldron, K. D. and B. M. Vinter. 1978. Ichthyoplankton of the eastern Bering Sea. Processed Rep., 88 p. Northwest and Alaska Fisheries Center, National Marine Fisheries Service, NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

and C. opilio have been found to frequently co-occur in research trawl catches with Pacific cod and pollock (Walters and McPhail 1982). Other abundant forms whose distribution overlaps that of the young Greenland turbot are the commercially sought snails (Neptunea and Buccinum) (MacIntosh 1980).

Age 1 Greenland halibut occur mainly where bottom water temperatures are 0-2°C, although in some years (e.g., 1979) some concentrations of these fish occurred in warmer waters (Fig. 10). They rarely are captured in any quantities within the bottom layer of cold water (less than 0°C), which is a persistent feature during the summer months, but appear to concentrate peripheral to this cold layer. In 1975, when surface ice covered much of the shelf in winter, this cold bottom water extended almost to the latitude of the Pribilof Islands. That summer, age 1 fish were concentrated just southeast of this cold water and were separated from the main mass of older fish on the shelf (compare Figs 10 and 11). In warm years when the cold layer is further north, age 1 fish are most available further north. There is then the impression that the position of high density of age 1 fish during the summer surveys is closely related to the southernmost extent of this cold bottom water layer.

As for older fish on the shelf (mainly age 2-4) they tended to be found in largest numbers during the summer surveys at outer shelf depths north of the Pribilof Islands and to the vicinity of St. Matthews Island (Fig. 11). In the earlier years of the summer surveys, these younger fish had a much broader distribution on the shelf than during the later years of the surveys (Fig. 11).

On the slope where the maturing and older fish are found, temperature conditions are relatively constant at bottom depths greater than 450 m and have a narrow range of 3 to 5°C; at the greatest depths of the Greenland halibut's distribution (730-1000 m) mean temperatures were 3 to 4°C. Wider temperatures (2-6°C) were recorded at shallower depths of the slope (184-450 m).

Patterns in the availability of fish from the analysis of fisheries data suggest both seasonal and long term movements of fish on the slope of the eastern Bering Sea. The distribution of older and larger fish in deepwater implies movements to deep water as the fish age. The gradation of small size fish from the northern slope to larger fish in the southern slope indicates also a southward movement as the fish age and mature (Fig. 12). Seasonal movements whether along the slope or by depth or both, are much more difficult to ascertain.

Several investigations have reported on such seasonal movements. For the eastern Bering Sea, Shuntov (1970) discussed seasonal depth movements of both young and older animals. Movement of young fish is confined to Continental Shelf depths. In spring, the movement is from deep parts of the shelf to shallower parts, followed by another movement to even shallower depths in summer. By fall, the fish have returned to deeper waters of the Shelf. The spring to fall movement is believed to occur in response to changes in water temperatures. For adults, he showed two concentrations of animals along the slope--one west and southwest of St. Matthew Island and the other further south between the Pribilof Islands and the Unimak Pass. He found that both concentrations of fish exhibited a spring to summer, feeding-related movement from deeper parts of the slope to shallow parts, followed by a return movement to deeper waters in October.

We attempted to identify seasonal movements of fish in the slope area of the eastern Bering Sea by examining commercial catch rates of the small Japanese freezer trawlers by depth, area, and season assuming that these rates reflected density. This is a questionable assumption since other factors besides density affects catch rates, such as selective targeting on certain size fish, preference for trawlable bottom, experience level of the fishermen, and changes in vulnerability and availability of the fish. Another assumption is that the catch and its size composition, and the effort to take that catch were accurately reported. In this examination, we partitioned the catch rate for each sex into two length groups. For males, these were fish less than 55 cm and fish 55 cm and greater; for females these were fish less than 70 cm and fish 70 cm and greater. This grouping separated each sex into mature and immature fish as suggested from length at maturity information from D'yakov (1982) and Smidt (1969).

The availability of fish in the smaller length groups was only examined for the northern and central slopes because of the small number of animals of these lengths taken from the southern slope. The CPUE of these small length groups was consistently much higher in the northern than in the central area particularly in the shallowest depth interval (Fig. 13). Their availability showed a pattern of high catch rates in the first two quarters, with the lowest catch rates usually occurring in the fourth quarter of the year. Their importance at all depths declined markedly in 1983 and 1984.

The lower catch rates of these smaller length groups in the last two-quarters cannot be explained by a movement of these fish to deeper water since fish of this length have never been observed in any quantities deeper than 730 m nor by movements to the shelf since there has been no evidence of high catch rates of this length group in either the fisheries or research trawl surveys at bottom depths of the shelf. A likely explanation is that these fish are either occurring more off the sea bottom and unavailable to bottom trawling or are dispersed or both during the summer and fall. Yang (1987)[7/] shows clearly the preference of these length fish for medium size nekton, such as pollock. During the first half of the year, feeding may be less intense than in the second half of the year, and the fish more aggregated and near bottom.

For fish in the larger length groups, some general tendencies were observed (Fig. 14). In all slope areas at the shallowest depth interval (184-450 m), the catch of both sexes tended to decline in the fourth quarter, whereas, in the deepest depth interval (>730 m) the catches tended to increase in the fourth quarter. This increase suggests an aggregating of the sexes and would agree with the belief that spawning begins in the late fall and occurs in the deep part of the slope. Another tendency was the decrease in the catches of males from the northern to southern slope and the converse for females (see also Fig. 12).

Prey-Predator Relationships of Greenland Halibut

Nektonic fishes are an important prey item of Greenland halibut in the North Pacific with pollock often a major component in the diet (Mikawa 1963; Shuntov 1970; Livingston et al. 1986; and Yang 1987[7/]). This may be because of the ubiquity and abundance of pollock in regions of Greenland halibut abundance.

The most detailed treatment of the feeding of Greenland halibut in the eastern Bering Sea is that of Yang (1987)[7/] who examined the stomach contents of fish of various lengths and from various bottom depths. He shows clearly an increase in prey size with increase in size of Greenland halibut and the preference for nektonic prey. At depths less than 200 m, young fish (less than 20 cm in length) were found to feed mainly on euphausiids, whereas, larger fish contained a high percentage by weight of young pollock. In the slope region there was a marked change in the diet of intermediate size fish (30-69 cm) with depth: squid followed by pollock at shallow depths of the slope, squid and eelpouts (Zoarcidae) at bottom depths of 400-599 m, and a diversity of prey (chiefly, rattails, Bathylagids, lanternfish, and squid) at depths greater than 600 m. Large Greenland halibut in the slope region were found to have fed mainly on large pollock.

Yang (1987)[7/] concluded that his findings continued to support those of others (DeGroot 1970; Bowering and Lilly 1985)[8/] that Greenland turbot forages some distance off the sea bottom. An exception might be the large Greenland halibut which may feed closer to the sea bottom as suggested by the presence of large pollock in their diet. Large pollock tend to be closer to the sea bottom than smaller pollock and are more available to bottom trawling.

Little is known about predation on Greenland halibut of the eastern Bering Sea and Aleutian Islands. Observations of Greenland halibut in stomachs of fish are rare. The Trophics Interaction Program at the Northwest and Alaska Fisheries Center in Seattle has examined over 15,000 stomachs of various fish species from the eastern Bering Sea and have found only a few instances of predation of Greenland halibut. These were yellowfin sole (Limanda aspera) and flathead sole feeding on young fish and some cannibalism as reported by Yang, 1987[7/]. Although, cod is very abundant in the eastern Bering Sea and is

7/ Yang, Mei-Sun. 1987. Food habits and daily ration of Greenland halibut (Reinhardtius hippoglossoides) in the eastern Bering Sea. M.S. Thesis, Univ. of Washington, Seattle, 57 p.

8/ Bowering, W. R. and G. R. Lilly. 1985. Diet of Greenland halibut off southern Labrador and northeastern Newfoundland (Div. 2J + 3K) in autumn of 1981-82, emphasizing predation on capelin. Northwest Atl. Fish. Org. SCR Doc. 85/109, Ser. No. N1085, 16 p.

actually a co-occurring species with Greenland halibut in research trawl catches (Walters and Smith 1982), there is no evidence of any serious predation of cod on Greenland halibut (Shimada et al 1986[9/]).

Among marine mammals, Kajimura (1984) has found that juvenile Greenland halibut (believed to be 0-age fish) was the 4th ranking fish species or group (by volume of prey) in stomachs of fur seals captured near the Pribilof Islands. In the three years (1964, 1973, and 1974) for which detailed information on the fur seal's feeding is available for the eastern Bering Sea, Greenland halibut comprised from 1.1 to 2.1% of fur seal stomach contents by volume (Fiscus and Kajimura 1965; Kajimura et al. 1974[10/]; Kajimura and Sanger 1975[11/]. This could translate into a large number of Greenland halibut (in excess of a billion fish) considering the population of lactating females (about 5 to 6 million), their period of foraging (June to November), and the assumption that the consumed Greenland turbot were fish in their first year of life.

Abundance

Measures of relative densities from research trawl surveys indicate that the abundance of the adult stock is centered on the slope of the southeastern Bering Sea and declines from east to west along the Aleutian Islands and towards the northwest in the eastern Bering Sea (Fig. 15). Low densities were found on the south side of the Aleutian Islands.

Absolute measure of abundance could not be estimated from age structured models (Pope, 1972) because of the lack of annual fisheries catch by age. Bakkala et al. (1987) provides biomass estimates for the eastern Bering Sea--Aleutian stock from stock reduction analysis (Kimura et al. 1984). This approach uses estimates of annual catch biomass, natural mortality, relative biomass change (CPUE), growth, and recruitment. Results from such an analysis suggest that the fishable biomass before any significant exploitation may have been a million t. The estimate for 1986 was about 400,000 to 450,000 t indicating a substantial decline in fishable biomass since pre-fisheries condition. These biomass figures are considered crude approximations.

A biomass estimate from research trawl surveys of the slope in 1979 and 1980 for the combined eastern Bering Sea and Aleutian Islands was 172,000 t, less than half the estimate from stock reduction analysis for recent years. Survey estimates are considered unreliable for measures of absolute abundance because of factors that make the Greenland halibut not fully available and vulnerable to the research trawl. The older and more powerfully swimming fish may avoid capture and some fish may be off the sea bottom foraging in upper waters or deeper than the maximum sampling depth. We do, however, assume that the surveys are providing measures of relative change. Such changes suggest that the biomass of adults (age 5 and older) in the slope have been declining in the eastern Bering Sea but increasing in the Aleutians (Fig. 16). This decline in the eastern Bering Sea is also indicated by annual changes in CPUE. Estimates of CPUE for the fisheries in the Aleutian Islands have not been made because of the lack of continuity in the data and the paucity of data in recent years.

In examining the CPUE of Japanese small freezer trawlers, a regression analysis using dummy variables was performed to determine effects in CPUE (tons per hour trawled) due to differences in area, season, and depth. A regression model with no interaction terms was used as a basis for the analysis, (Table 5). Though interactions may well exist they were not included in

9/ Shimada, A. M., P. A. Livingston, and J. A. June. 1986. Summer feeding of Pacific cod, Gadus macrocephalus, on the eastern Bering Sea Shelf. Unpubl. manuscr., Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Seattle, WA 98112.

10/ Kajimura, H., G. Sanger, and C. H. Fiscus. 1974. Pelagic, Bering Sea. In Fur Seal Investigations, 1973, U.S. Dep. Commer., NMFS, NWAFC, Seattle, WA p. 37-39.

11/ Kajimura, H. and G. A. Sanger. 1975. Pelagic - Bering Sea. In Marine Mammals Division, Fur Seal Investigations, 1974. U.S. Dep. Commer., NMFS, NWAFC, Seattle, WA p. 38-54.

the model since there were enough empty cells to cause the hat matrix to appear nonsingular due to rounding error; tolerances for interaction terms were too low to allow their inclusion in the model (Draper and Smith 1981; Weisberg 1985). The results of the regression analysis suggest that all effects were both meaningful and significant (Table 6). Statistical significance of a factor depends on the significance of its representative dummy variables as a group, not the significance of individual coefficients representing separate levels of a factor. For the regression model results in Table 6 all factors were statistically significant at $\alpha = 0.05$; the p-value for each group effect was always less than 0.025. By area the highest regression coefficient was found for the southern slope area (Fig. 17), where the CPUE for most years was greater than that of other areas for comparable years. By quarter, the greatest deviation of the regression coefficient from the standard (third quarter) was estimated for the first quarter, where the CPUE tended to be consistently higher annually than in the other quarters. By depth the greatest deviation of the regression coefficient was estimated for the shallowest interval fished (184-450 m), where the CPUE was almost invariably less than at the greater depths. Whether we look at CPUE by area, quarter, or depth, it is obvious that CPUE tended to peak in 1980 and then reach a low point in 1982 or 1983 (Fig. 18). The regression coefficient for annual effect reflects this tendency by being the highest in 1980 and lowest in 1982 and 1983.

When the CPUE in weight is converted to CPUE in numbers, a somewhat different annual trend was found. For the Northern and Central Slope areas, CPUE in numbers peaked in 1980 and declined to low levels in 1983 and 1984 (Fig. 5).

The regression analysis has not been updated using the more recent 1985 data. But for 1985, CPUE in both tons and number per hour increased. In the face of declining recruitment to the adult stock and the decline of the adults as indicated from research trawl surveys, the rise in CPUE may be reflecting either changes in the vulnerability or availability of the fish to the fisheries or more likely changes in fishing efficiency. Since 1983, fishing effort of the small freezer trawlers have sharply declined. There has also been an effort by the fishers to avoid high bycatches of species having low annual quotas such as sablefish, which is often taken with Greenland halibut. Once the small quota of sablefish is reached, even as bycatch, the fisheries are closed. Therefore, in the past when the foreign quota of sablefish was still relatively high, the small freezer trawlers may have been less descriminant. In recent years, they may have been forced to be more selective towards species such as Greenland halibut. These are speculations for we have no evidence that such a change has occurred in the fisheries. The unexpected rise in CPUE is yet to be definitively explained.

As for the young Greenland halibut, their abundance has dramatically declined on the shelf of the eastern Bering Sea (Fig. 19). In the early years of the present surveys Greenland halibut were caught throughout the shelf region, though mainly at intermediate (50-100 m) and outer shelf depths (101-200 m). With time, the geographical catch distribution shrank so that by 1984 and 1985 only the area west and south of St. Matthew Island was yielding any amount of fish (Fig. 20). Within that area, the magnitude of the catches has decreased over time.

The 1978 year class was the last one encountered in any large numbers in research surveys on the shelf. Therefore, there has been a series of poor year classes (1979-85). A measure of the strength of the 1986 year class as 1-year olds will be determined from the results of the 1987 research survey. Recruitment to the adult stock of the slope will continue to be poor until at least 1990.

In summary, there is evidence that the population of Greenland halibut of the eastern Bering Sea and Aleutian Islands is declining as well as ageing. This is caused by the continued decline in young fish recruiting to the population of the slope and to the fisheries which removed disproportionately large amounts of the smaller fish through their greater fishing pressure in the northern slope region of the shelf (Fig. 4) where the greatest proportion of small fish (30-55 cm) occur. This recruitment failure is reflected in the decline of small size fish in the slope area of both the eastern Bering Sea (Fig. 21) and Aleutian Islands (Figs. 21 and 22) and the increase in the average weight of individual fish (Figs. 5 and 16). Although the relative abundance of fish in the eastern Aleutians has been increasing, this is interpreted as a result of low exploitation of the fisheries in this region compared to the eastern Bering Sea coupled with increases in population because of long term movements of fish from the eastern Bering Sea. The total stock, however, is considered to be declining.

DISCUSSION

Greenland halibut of the eastern Bering Sea and Aleutian Islands have certain features they share with the North Atlantic form. There is an apparent bathymetric gradient involving fish size and age with the younger animals occupying shallow depths and the older animals residing at depths of the slope. At shallow depths, namely that of the shelf, the young animals can be exposed to subzero temperatures but tend to be associated with 0° to 4°C waters. On the slope, the adults are often found in greatest numbers where bottom water temperatures apparently undergo little annual or seasonal change. For maintenance of sizeable populations of adults, a relatively broad shelf with relatively cold bottom waters appear to be needed for the successful settling of the larvae and the growth of young fish as seen in the eastern Bering Sea. There seems to be no doubt that Greenland halibut prefer nektonic prey as shown by various food habit studies of fish from north Pacific and north Atlantic waters. This off-the-sea-bottom foraging makes the fish unavailable to bottom trawling at times and may explain to some degree temporal changes in CPUE by the fisheries and low estimates of absolute abundance derived from research bottom trawl surveys. The search for food and reproductive demands results in seasonal shifts in abundance.

We were not able to discern any long-distance seasonal migrations of eastern Bering Sea fish related to spawning and feeding as reported for the northwestern Atlantic stock (Bowering, 1984) and the Icelandic stock (Sigurdsson, 1979). However, our findings do suggest a long-term movement of maturing fish from the northwest slope of the eastern Bering Sea towards the predominantly mature population in the central and southern slope areas where major spawning is believed to take place. Similar movements of maturing animals towards the region of major spawning have been alluded to for the Greenland halibut stock of the northwestern Atlantic and the one off Norway. Bowering (1984) has presented evidence that maturing fish move from the Newfoundland-Labrador area to the spawning grounds in Davis Strait, and he raises the possibility that these fish may remain in that vicinity, namely off West Greenland. Based on north-south increases in fish size and tagging results for the stock off Norway, Godo and Haug (1987), hypothesize a movement of animals south to the spawning grounds between Spitsbergen and northern Norway. For the Bering Sea, this southward movement of fish along the slope is considered only part of a long term movement during which the young animal develops and matures before becoming a member of the spawning population.

We offer a hypothesis as to the details of this long term movement for the eastern Bering Sea and Aleutian Islands stock. We begin with the assumption (supported by findings presented by Bulatov 1983 and Waldron 1981) that major spawning occurs in the deep part of the slope north of Unimak Pass and Unalaska Island in the late fall and winter. Larvae are carried northward by the Bering Slope current (Kinder et al., 1975), although side eddies may sweep larvae seaward as well as shoreward onto the shelf. Kinder and Shumacher (1981) mention some flow across the shelf from the vicinity of Unimak Pass. Waldron (1981) shows highest catches of larvae during the spring-summer period in the vicinity of the shelf's edge and slope, with small catches scattered in the shelf region and a few occurrences over deep water; larvae were found as far north as the vicinity of St. Matthew Island. A fall settling of the larvae is suggested from the reports of Hognestad (1969), Smidt (1969), and Atkinson, et al. (1981)[12/] for the North Atlantic form of the species. However, in the eastern Bering Sea, a small number of 0-group fish were found during July and August surveys of the shelf, implying that some larvae apparently settle earlier than the fall in this region. What happens to these young-of-the-year fish during the winter months is unknown, but by the following summer they tend to be concentrated near the southernmost extent of the cold bottom layer of less than 0°C. By their second summer, they are found in largest numbers with older fish (mainly ages 3 and 4) in the region of the outer shelf north and northwest of the Pribilof Islands. We propose that from this relatively high density area that a majority of older fish on the shelf move onto the

12/ Atkinson, D. B., W. R. Bowering, SV. AA. Horsted, J. P. Minet, and D. G. Parsons. 1981. A review of biology and fisheries of roundnose grenadier (*Macrourus rupestris*), Greenland halibut (*Reinhardtius hippoglossoides*), and shrimp (*Pandalus borealis*) in Davis Strait (NAFO Subareas 0 and 1). Northwest Atl. Fish. Org. Scr. Doc. 81/VI/22, Ser. No. N290:7-27.

slope. The area lies adjacent to the northern slope (Fig. 2) where we found the highest proportion of older immatures (30-55 cm fish) in the trawl fisheries catch (Fig. 12) and the highest catch rates in numbers of fish (Fig. 5). We assume a southward movement of these animals as they age towards the predominantly mature fish of the southern slope based on the increasing proportion of larger fish in the fisheries catch from north to south (Fig. 12).

For the Aleutian Islands region, we hypothesize that spawning takes place there because of the presence of large, mature fish year-around. However, due to the lack of any extensive shelf, and perhaps because of currents, there is little successful settling of the larvae in this region as suggested by the infrequent encounters of small fish (less than 35 or 40 cm in length) in this region by research surveys and fisheries. The eastward directed current on the northern side of the Aleutians (Kitani 1983[13/]) could be a means by which eggs and larvae would be transported towards the broad shelf area of the southern part of the eastern Bering Sea. We assume that most adult fish in the Aleutians spent their juvenile stages in the shelf region of the eastern Bering Sea.

The decline in the proportions of the smaller immatures in both the eastern Bering Sea and Aleutian Islands region during a similar time period (1981-83) suggest a common source of recruitment--the eastern Bering Sea Shelf. The rise in abundance in the eastern Aleutians while abundance in the eastern Bering Sea was declining is interpreted as the result of movement of adult fish from the eastern Bering Sea to the Aleutians. Since abundance appears to be increasing in the Aleutians, the rate at which fish are moving into the Aleutians may be exceeding the mortality rate, namely from natural causes since removals by the fisheries have been negligible. The evidence so far continues to support the management of the eastern Bering Sea and Aleutian Islands fish as one stock.

One concern about this stock is its northern extension into waters of the Bering Sea under the jurisdiction of the USSR, namely the Gulf of Anadyr and the region off Olyutorski Bay. How abundant are these fish in these waters, and what is the nature of exchange of these fish with those in the U.S. Fishery Conservation Zone? Conceivably, fish could be moving from USSR to US waters, and this may be important in slowing the current rate of decline of the eastern Bering Sea population.

Another concern is the continuing recruitment failure. We are assuming that this failure is real based on research trawl surveys and fisheries findings. Some doubt is expressed, however, because of the absence of surveys in the northern part of the eastern Bering Sea shelf. What we perceive as a decline in young fish abundance may in actuality be the results of a distributional shift of the young fish towards the north and beyond the research trawl survey area. We raise this as a possibility, although the decline of intermediate length fish (30 to 55 cm) on the slope would argue against this. If the year class decline is indeed occurring, what circumstances are bringing this about?

Several events have occurred or are occurring, which may bear on recruitment failure in Greenland halibut. The spawning stock has been declining, but we have no understanding as to the relationship of spawners to the number of recruits to give us any guidelines for considering the possibility that recruitment failure may be the result of an insufficient number of spawners.

Other events have been the major increases in fish populations that may predate on the young Greenland halibut. Pacific cod biomass increased 4-5 fold between 1976 and 1979 and then continued to increase, reaching slightly over a million t in 1986 (Thompson and Shimada 1986). In regions of the shelf where Greenland halibut have historically been abundant, cod abundance increased sharply between 1975 and 1979. Pacific cod may be an important predator of Greenland halibut, based on overlapping distributions, an inverse relationship in their abundance, and the inference that if Atlantic cod preys on young Greenland halibut, then its congener may also have this potential. However, findings by Shimada et al.,[9/] based on the examination of over 1,850 cod stomachs collected in 1981 from the eastern Bering Sea, suggest that Greenland turbot is of little consequence in the cod's diet. But this may be a reflection of the narrow time and area window of their

13/ Kitani, Kozo. 1983. Water movement in the Aleutian Basin in winter, 1983. (Document submitted to the International North Pacific Fisheries Commission). 8 p. Fisheries Agency of Japan, Tokyo, Japan 100.

sampling. There were no samples collected from the fall period when most of the settling of young fish is believed to occur.

Other fish populations that have increased are those of arrowtooth flounder and sablefish (potential predators of Greenland halibut in its pelagic stage on the slope and outer shelf regions) and yellowfish sole and flathead sole, which could consume the recently settled larvae at midshelf depths. As with cod, we have no hard evidence that these populations are important predators of young Greenland halibut.

Our best indications of important predation on the young stages of Greenland halibut comes from Kajimura (1984) in his report on the diet of the northern fur seal. Fur seals have been in the Bering Sea in large numbers for a long time, but why should they suddenly begin to seriously reduce the abundance of young Greenland halibut? Perhaps predation by fur seals along with that of increased predation by other species could be accounting for the year class decline.

An obvious potential source of serious mortality of the young would be the trawl fisheries on the shelf. In the years 1977-79, the Japanese mothership fishery took a considerable number of Greenland halibut as a bycatch in their pollock fisheries. This bycatch amounted to an average of some 41 million animals a year. Yet these removals were only a small fraction (<5%) of the animals estimated to be in the shelf area by NMFS surveys in 1979 and 1980. Such removals should have had no serious impact on the abundance of young fish, and are inconsequential compared to the decline of Greenland halibut between 1980 and 1981 on the shelf.

We have yet to make a serious effort to examine for changes in the physical environment that may be associated with recruitment failure. There have been cold years as well as warm years in the Bering Sea. The winters of 1974-75 and 1975-76 were exceptionally cold, with ice extending as far south as the Pribilof Islands (Niebauer, 1983). In subsequent years, a warming trend occurred and the extent of the ice cover became minimal in the winter of 1978-79. By the following winter, however, ice cover began to increase again and became more extensive still in 1980-81. Abundant year classes were produced both in cold years (1975 and 1976) and in a warm year (1978); weak year classes have been occurring since 1980, a period having warm as well as cold years. Thus, year class strength seems to be independent of cold conditions based on this superficial examination.

As in many attempts to explain changes in the year class strength of a species, there is no concrete evidence for a particular causative factor or factors. Several possibilities have been discussed for the purpose of evaluating either their plausibility or their promise as avenues for further study. We are left with a considerable degree of uncertainty as to the causes for the continuing decline in the year class abundance of Greenland halibut.

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Table 1.--Commercial catches of Greenland turbot (t) from the northeast and northwest Atlantic Ocean and from the eastern Bering Sea and Aleutian Islands region of the Pacific Ocean (catch statistics from International Council for the Exploration of the Seas 1972-83; Northwest Atlantic Fisheries Organization 1983; Bakkala et al. 1985).

Area	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	Accumulative total
NORTHEAST ATLANTIC (ICES)													
Barents Sea	4,011	5,399	8,548	5,667	5,251	6,495	2,479	2,273	1,591	945	602	1,230	44,491
Norwegian Sea	12,819	10,504	14,564	8,190	7,852	3,166	3,985	10,396	12,892	10,287	5,473	5,284	105,412
Spitzbergen-Bear Island	53,925	60,182	18,310	16,081	24,660	28,511	29,610	16,221	10,134	6,080	7,209	8,504	279,427
North Sea & English channel	5		30	49	34	17	21	12	33	21	216	7	445
Iceland	15,043	11,732	10,507	7,386	7,866	3,308	5,448	15,679	11,588	16,976	27,927	15,780	149,240
Faroes, NW Scotland, N. Ireland & N. of Azores		11	498	403	334	586	333	661	731	566	1,342	580	6,045
East Greenland	841	10,422	8,061	12,719	28,089	19,627	273	241	2,166	6,231	2,148	2,893	93,711
TOTAL	86,644	98,250	60,518	50,495	74,086	61,710	42,149	45,483	39,135	41,106	44,917	34,278	678,771
NORTHWEST ATLANTIC (ICNAF)													
West Greenland	2,000	3,000	4,000	7,000	13,000	23,000	11,000	9,000	11,000	18,000	7,000	6,000	114,000
Baffin Island	+	1,000	10,000	2,000	1,000	2,000	5,000	4,000	1,000	1,000	2,000	+	29,000
Labrador	11,000	11,000	13,000	15,000	16,000	12,000	9,000	11,000	7,000	6,000	2,000	5,000	118,000
Newfoundland	26,000	14,000	17,000	15,000	12,000	17,000	16,000	21,000	32,000	29,000	31,000	26,000	256,000
Gulf of St. Lawrence & Nova Scotian shelf	1,000	1,000	1,000	1,000	1,000	2,000	2,000	4,000	7,000	9,000	7,000	3,000	39,000
TOTAL	40,000	30,000	45,000	40,000	43,000	56,000	43,000	49,000	58,000	63,000	49,000	40,000	556,000
EASTERN BERING SEA & ALEUTIAN ISLANDS AREA	19,976	42,214	77,384	63,946	78,442	67,789	62,590	30,161	42,189	41,409	52,552	57,321	635,973

Table 2.--Annual catches of Greenland halibut (in 1,000 t) in the eastern Bering Sea and Aleutian Islands region as reported by Bakkala et al. (1986) for 1970-76 and by the U.S. Observer Program for 1977-86.

EASTERN BERING SEA

Nation	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Japan	14.7	30.2	49.8	43.4	58.8	52.6	51.6	33.6	54.7	42.4	46.9	50.5	44.0	42.2	21.1	14.6	6.8
USSR	5.0	10.3	14.7	11.9	10.8	12.2	8.9	2.7	4.9	0.5	--	--	--	--	tr	--	--
Other	--	--	--	--	--	--	--	--	0.1	0.2	2.0	2.4	1.8	1.2	0.2	tr	0.9
Total	19.7	40.5	64.5	55.3	69.6	64.8	60.5	36.3	59.7	43.1	48.9	52.9	45.8	43.3	21.3	14.6	7.7

ALEUTIAN ISLANDS REGION

Nation	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Japan	0.3	1.7	12.7	8.3	8.8	3.0	2.0	1.7	8.2	9.9	3.7	4.4	6.3	4.1	1.8	tr	0.1
USSR	--	--	0.2	0.3	tr	--	0.1	tr	tr	tr	--	--	--	--	--	--	--
Others	--	--	--	--	--	--	--	--	tr	tr	tr	tr	tr	tr	tr	tr	2.0
Total	0.3	1.7	12.9	8.6	8.8	3.0	2.1	1.7	8.2	9.9	3.7	4.4	6.3	4.1	1.8	tr	2.1
Grand Total	20.0	42.2	77.4	63.9	78.4	67.8	62.6	38.0	67.9	53.0	52.6	57.3	52.1	47.5	23.1	14.7	9.8

tr = catch of 50 t or less

Table 3.--Annual catch of Greenland halibut (in 1,000 t) in the Japanese fisheries of the eastern Bering Sea and Aleutian Islands region. Statistics were provided by the *U.S.* Observer Program.

EASTERN BERING SEA

Fishery or Vessel Class	1978	1979	1980	1981	1982	1983	1984	1985
Small freezer trawlers[1/]	38.4	30.1	33.3	41.2	38.1	38.2	19.9	14.2
Mothership	11.9	9.8	9.8	5.4	2.8	1.7	0.7	0.3
Other trawler types	3.1	0.7	0.3	0.5	0.2	0.1	0.1	tr
Longline	1.3	1.8	3.3	3.4	2.9	2.2	0.4	0.1
Total	54.6	42.4	46.7	50.5	44.0	42.2	21.1	14.6

ALEUTIAN ISLANDS REGION

Fishery or Vessel Class	1978	1979	1980	1981	1982	1983	1984	1985
Small freezer trawler[1/]	6.7	8.9	3.2	4.1	6.0	3.9	1.6	--
Other trawler types	0.4	0.1	tr	tr	tr	tr	tr	--
Longline	1.1	0.9	0.5	0.3	0.3	0.2	0.2	tr
Total	8.2	9.9	3.7	4.4	6.3	4.1	1.8	tr

1/ Combined catches of two major Japanese fisheries - North Pacific Trawl Fishery and the Landbased Dragnet Fishery
tr = catch of 50t or less.

Table 4.--Relative population numbers of Greenland halibut (million fish) by age groups and year class as estimated from bottom trawl surveys in a standard area of the eastern Bering Sea shelf.

Year Class	Ages 1	2	3	4	5+
1975	*	*	*	137	15
1976	*	*	247	195	21
1977	*	202	192	105	19
1978	290	248	101	30	14
1979	75	36	13	18	*
1980	17	10	10	*	6

* No estimate

Table 5.--Regression model (no interactions) that was applied to Greenland halibut CPUE of the eastern Bering Sea

Model	Effects
CPUE = B_o[1/] (intercept)	
$+ B_1D1 + B_2D2$	Depth
$+ B_3Y1 + B_4Y2 + B_5Y3 + B_6Y4 + B_7Y5 + B_8Y6$	Year
$+ B_9Q1 + B_{10}Q2 + B_{11}Q3$	Quarter
$+ B_{12}A1 + B_{13}A2$	Area

Definition of Dummy Variables

Depth		D1	D2
Standard:	451-730	0	0
	184-450	1	0
	>730	0	1

Year		Y1	Y2	Y3	Y4	Y5	Y6
Standard:	83	0	0	0	0	0	0
	78	1	0	0	0	0	0
	79	0	1	0	0	0	0
	80	0	0	1	0	0	0
	81	0	0	0	1	0	0
	82	0	0	0	0	1	0
	84	0	0	0	0	0	1

Quarter		Q1	Q2	Q3
Standard:	July-Sept.	0	0	0
	Jan.-Mar.	1	0	0
	Apr.-June	0	1	0
	Oct.-Dec.	0	0	1

Area		A1	A2
Standard:	Northern	0	0
	Central	1	0
	Southern	0	1

1/ B_o is the intercept or standard and b_i is the departure from the standard because of a specific main effect

Table 6.--Results of regression analysis of CPUE of Greenland halibut of Japanese class 2 freezer trawlers operating in the eastern Bering Sea, 1978-1984. Data are from U.S. Observer Program.

Multiple R	0.5022	Std. error of est.	0.2077
Mulitiple R-square	0.2522		

Analysis of Variance

	Sum of squares	DF	Mean square	F ratio	P(tail)
Regression	6.3588	13	0.4891	11.335	0.0000
Residual	18.8572	437	0.0432		

Variable[2]		Coefficient	Std error	Std Reg coeff	T	P(2 tail)	Tolerance
		0.19464[1]					
Depth:	184-450 m	-0.10259	0.02236	-0.210	-4.588	0.0000	0.81856
	>730 m	0.05838	0.02619	0.104	2.229	0.0263	0.78612
Year:	1978	0.09639	0.03418	0.148	2.820	0.0050	0.62448
	1979	0.12133	0.03532	0.177	3.435	0.0006	0.64679
	1980	0.25440	0.03840	0.332	6.624	-0.0000	0.68218
	1981	0.21433	0.03632	0.301	5.902	-0.0000	0.65708
	1982	0.04024	0.03353	0.063	1.200	0.2307	0.61396
	1984	0.14003	0.03584	0.201	3.907	0.0001	0.64582
Quarter:	Jan-Mar	0.13014	0.03231	0.191	4.028	0.0001	0.76262
	Apr-Jun	0.01373	0.02589	0.026	0.531	0.5960	0.73892
	Oct-Dec	-0.01074	0.02580	-0.020	-0.416	0.6773	0.75678
Area:	Central	0.04516	0.02259	0.095	1.999	0.0462	0.75849
	Southern	0.13429	0.02860	0.232	4.696	0.0000	0.70360

[1] Intercept

[2] All group effects were statistically significant at = 0.05

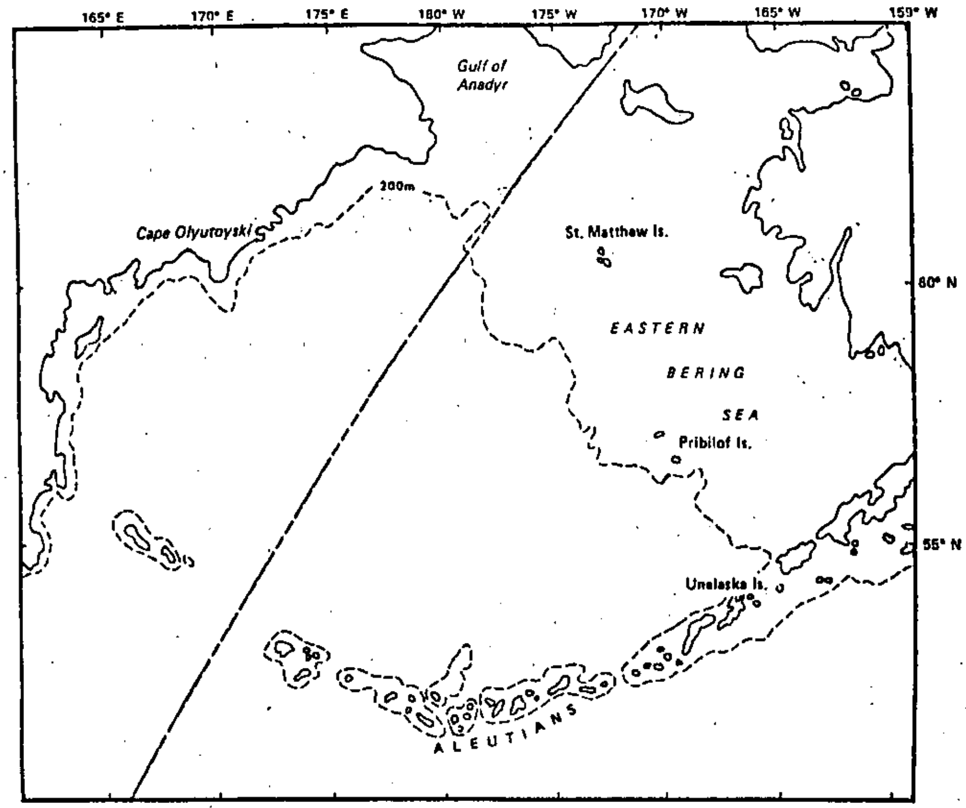

Figure 1.--The Bering Sea.

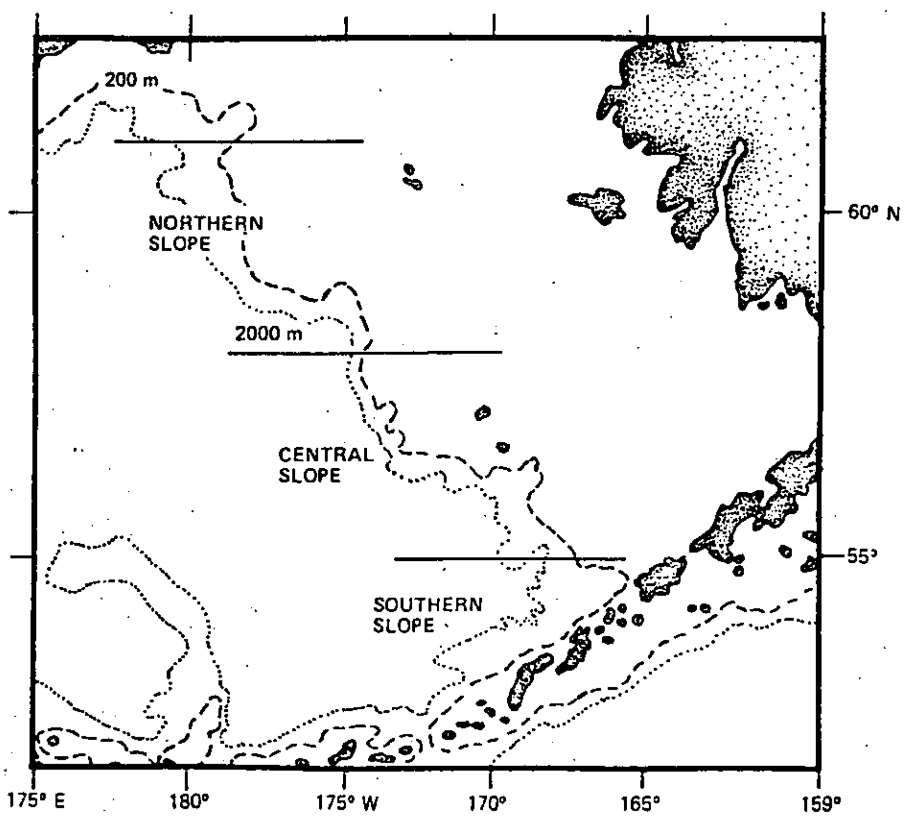

Figure 2.--Location of the three continental slope areas referred to in the presentation of fisheries and research survey findings.

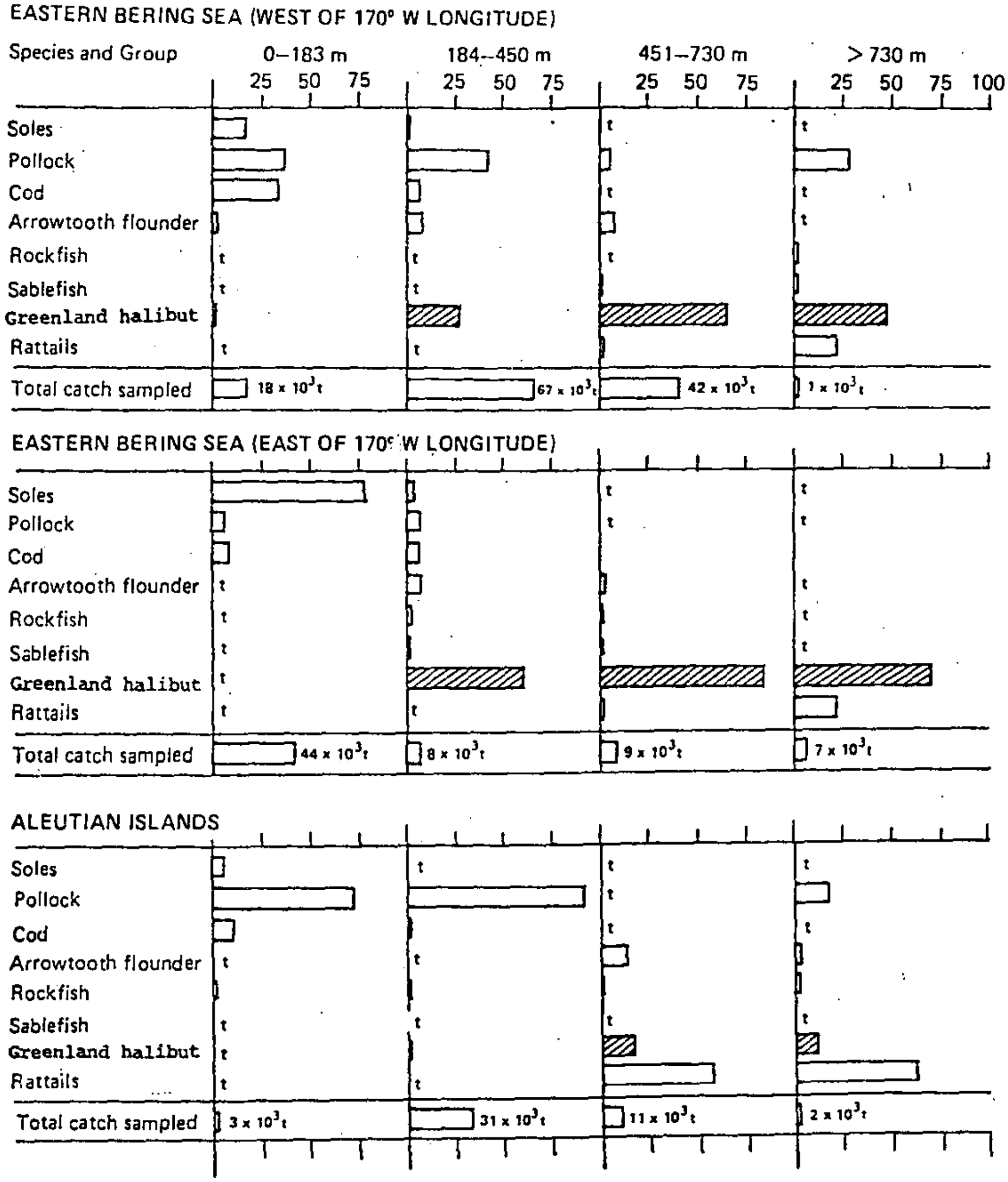

Figure 3.--Importance of Greenland halibut relative to other species in the catch of Japanese small trawlers in the eastern Bering Sea and Aleutians, 1980-84. Total catch refers to that taken by trawlers with U.S. observers aboard.

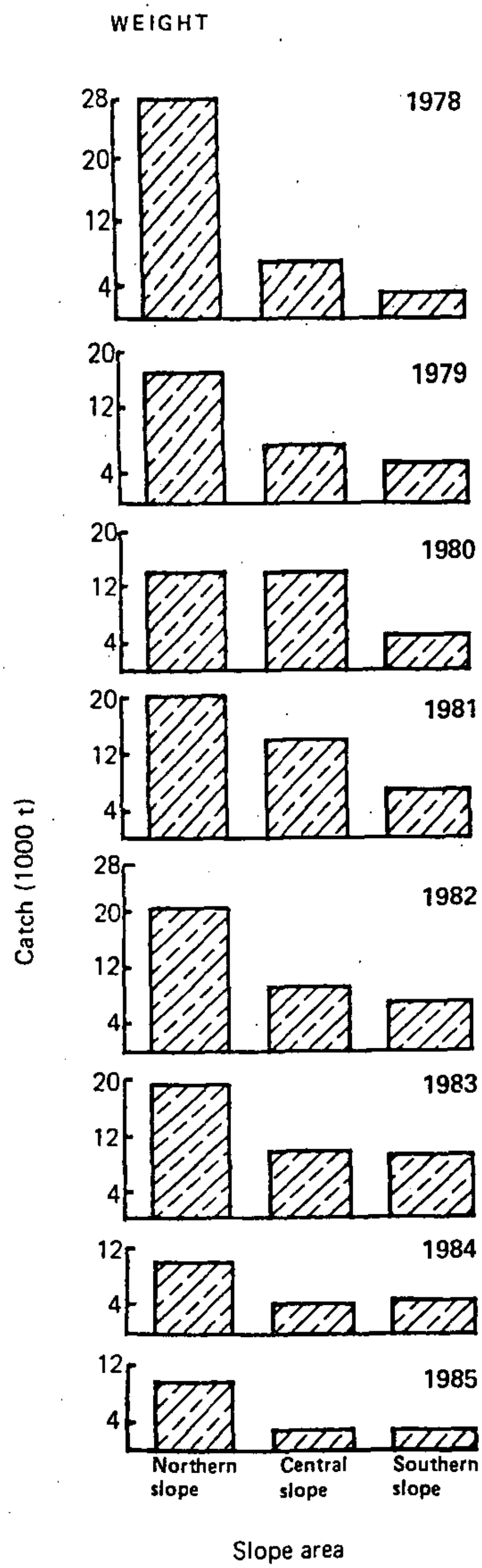

Figure 4.--Annual Greenland halibut catch of Japanese small trawlers in the continental slope region of the eastern Bering Sea, 1978-85.

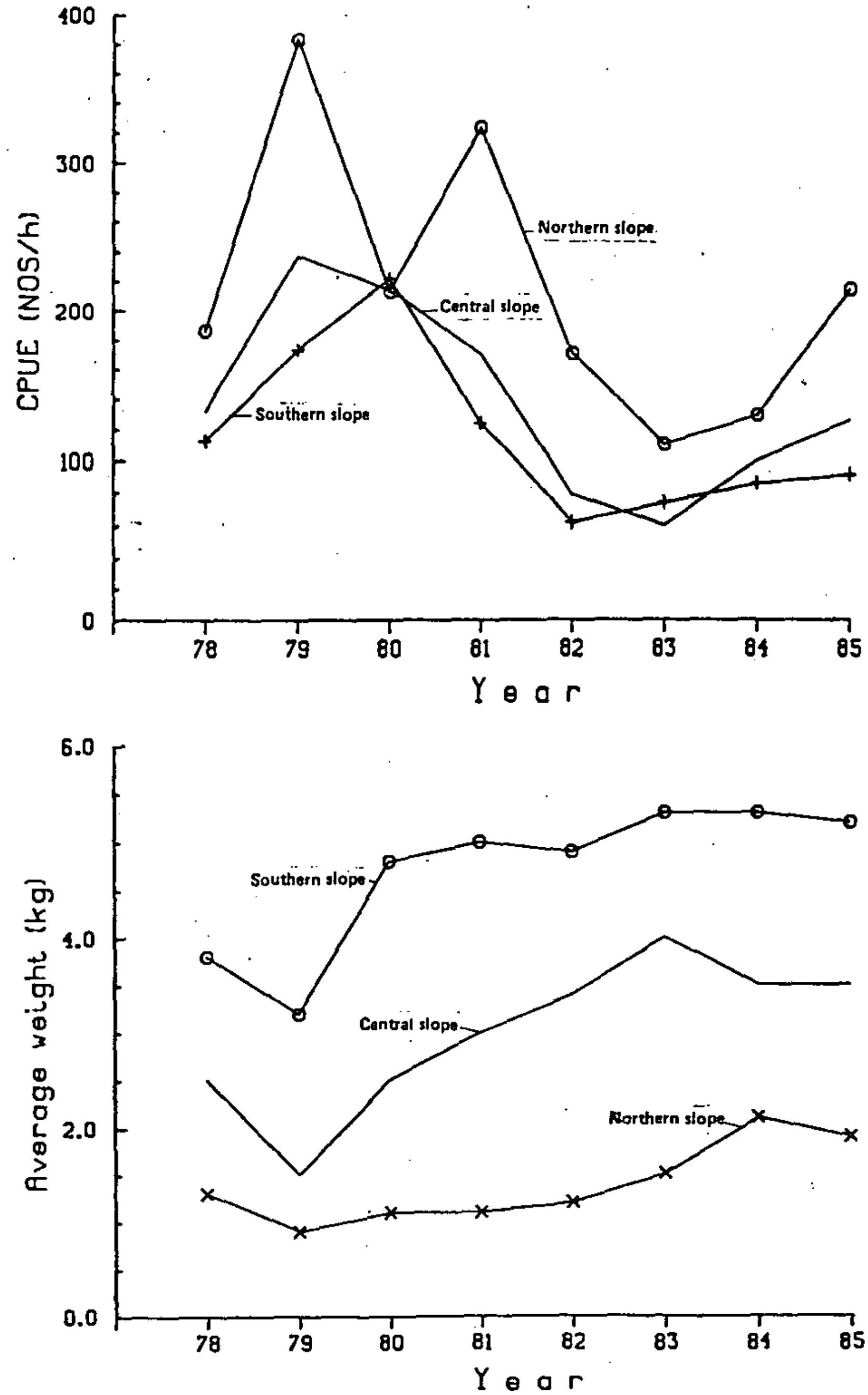

Figure 5.--Annual changes in CPUE by number and average weight of Greenland halibut (from sampling aboard Japanese small trawlers.

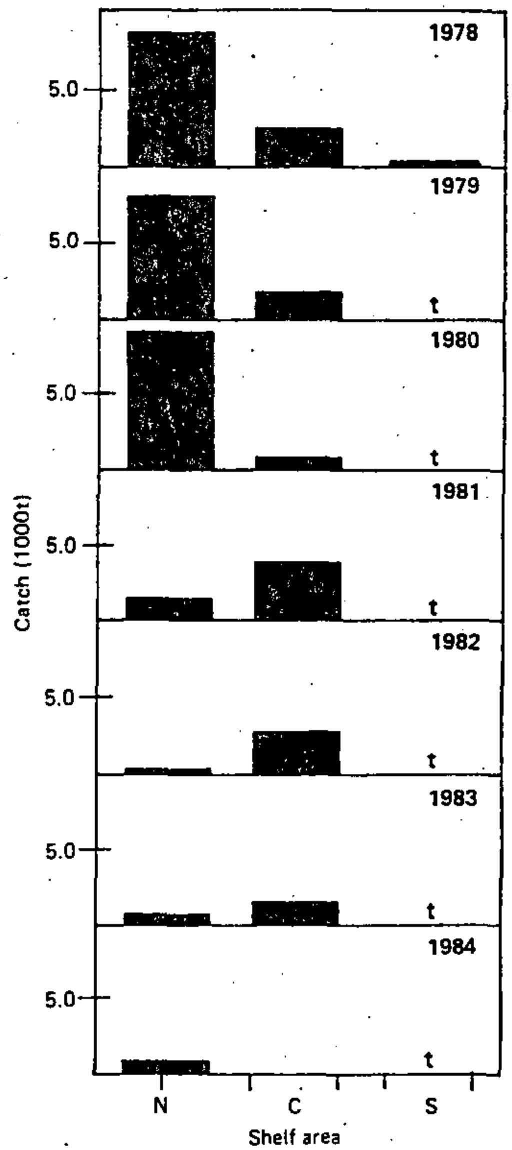

Figure 6.--Annual catch of Greenland halibut by the Japanese surimi mothership fishery by area of the eastern Bering Sea shelf and (N = North of 58°, C = 55°-58°N lat., and S = South of 55°N lat.).

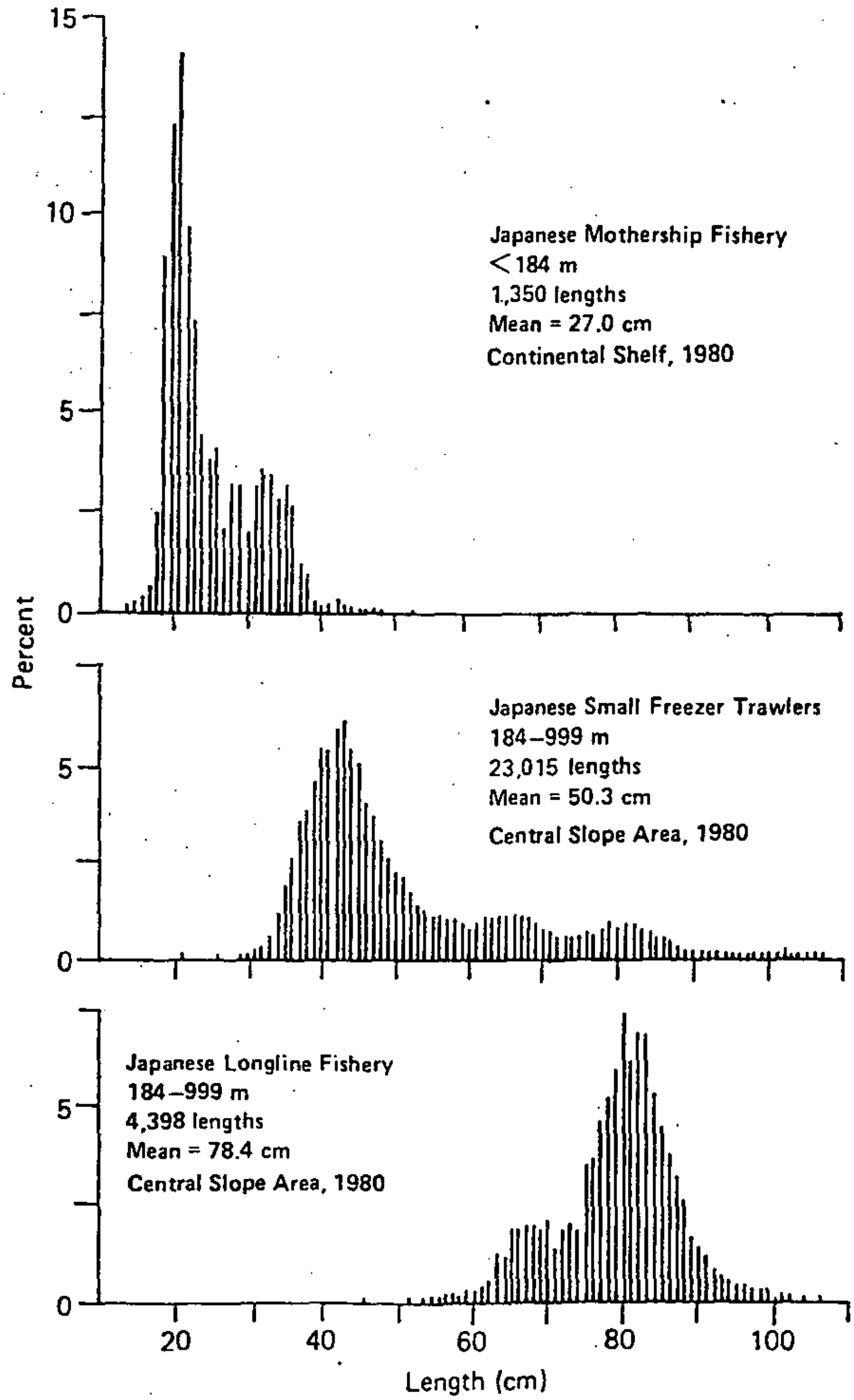

Figure 7.--Length composition of Greenland halibut taken by the various Japanese fisheries in the eastern Bering Sea.

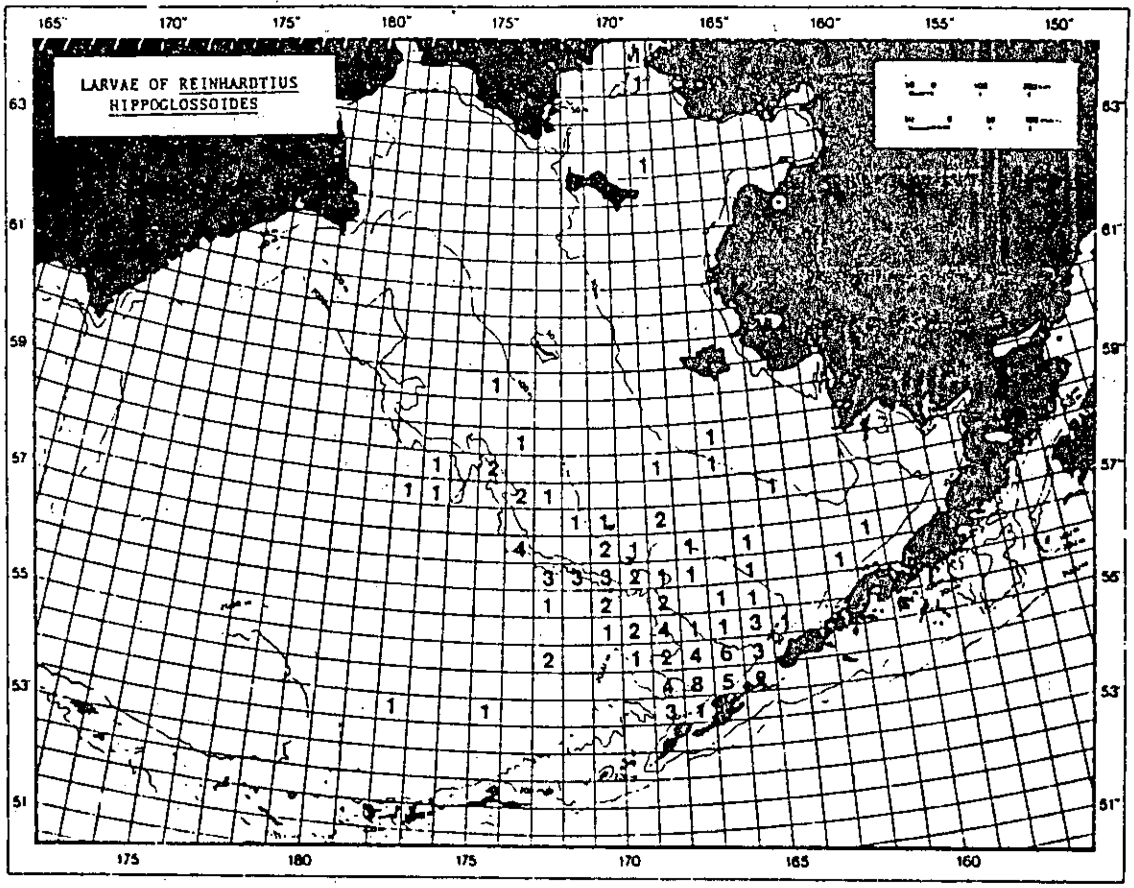

Figure 8.--Number of stations where larvae of Greenland habitat were caught during ichthyoplankton surveys (from Waldron 1981).

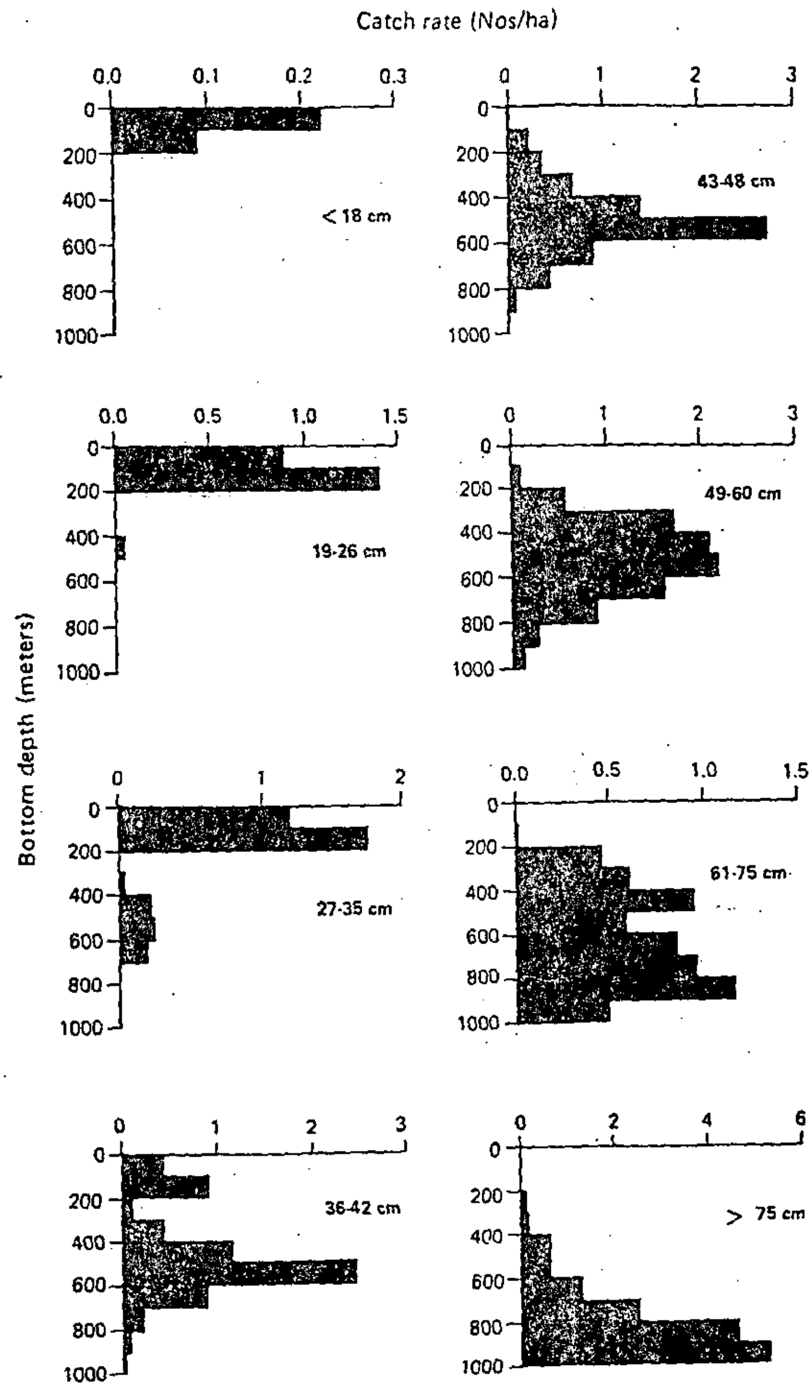

Figure 9.--Length composition of female Greenland halibut related to depth of capture during the 1979 U.S.-Japan cooperative surveys of the eastern Bering Sea.

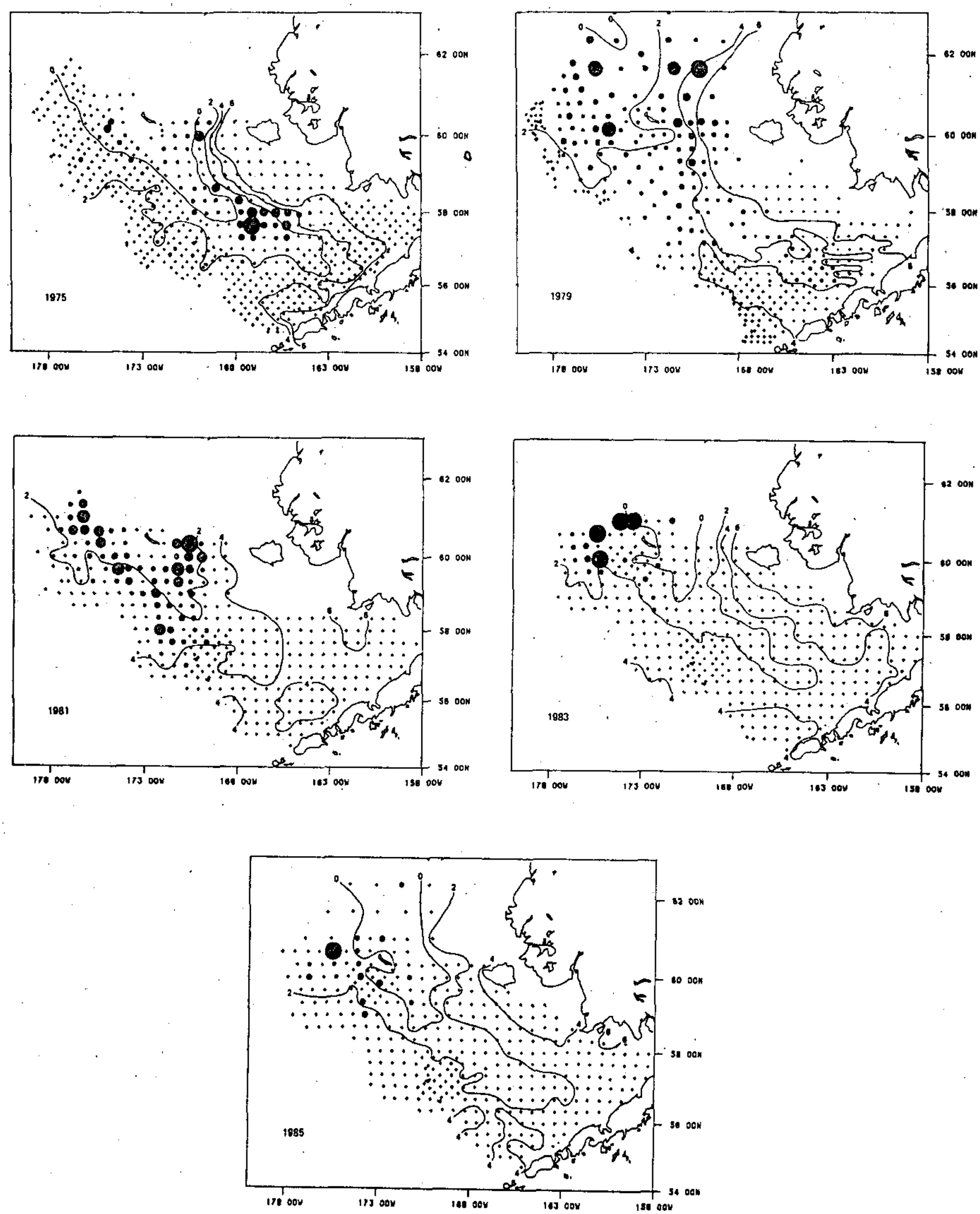

Figure 10.--Relative density distribution of age 1 Greenland halibut (less than 19 cm in length) and bottom water temperatures as observed during NWAFC research bottom trawl surveys on the shelf. (Dot sizes are relative to year only and cannot be used for interyear comparisons). Plus signs refer to station locations.

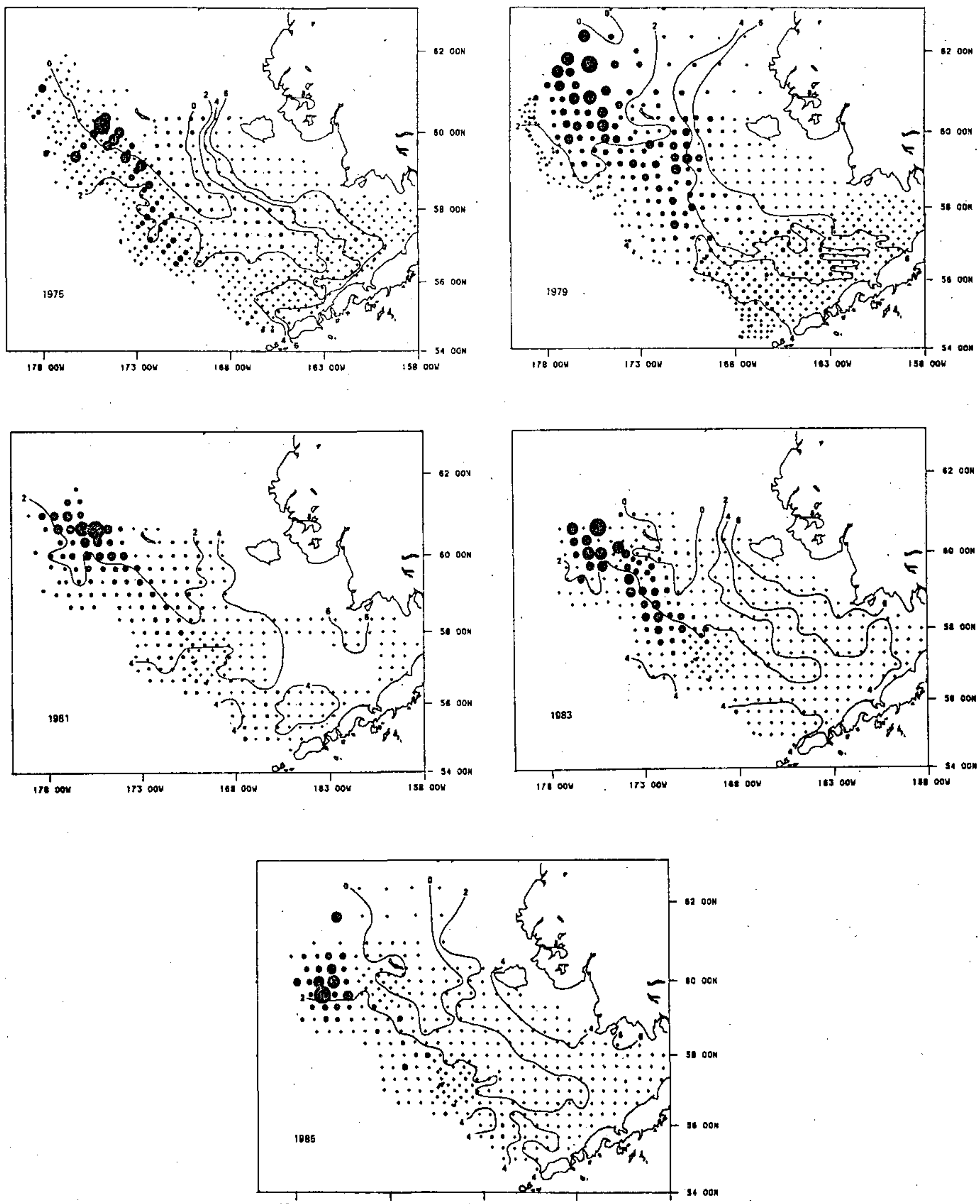

Figure 11.--Relative density distribution of age 2 and older Greenland halibut (greater than 19 cm in length) and bottom water temperatures as observed during NWAFC research bottom trawl surveys on the shelf. (Dot sizes are relative to year only and cannot be used for interyear comparisons). Plus signs refer to station locations.

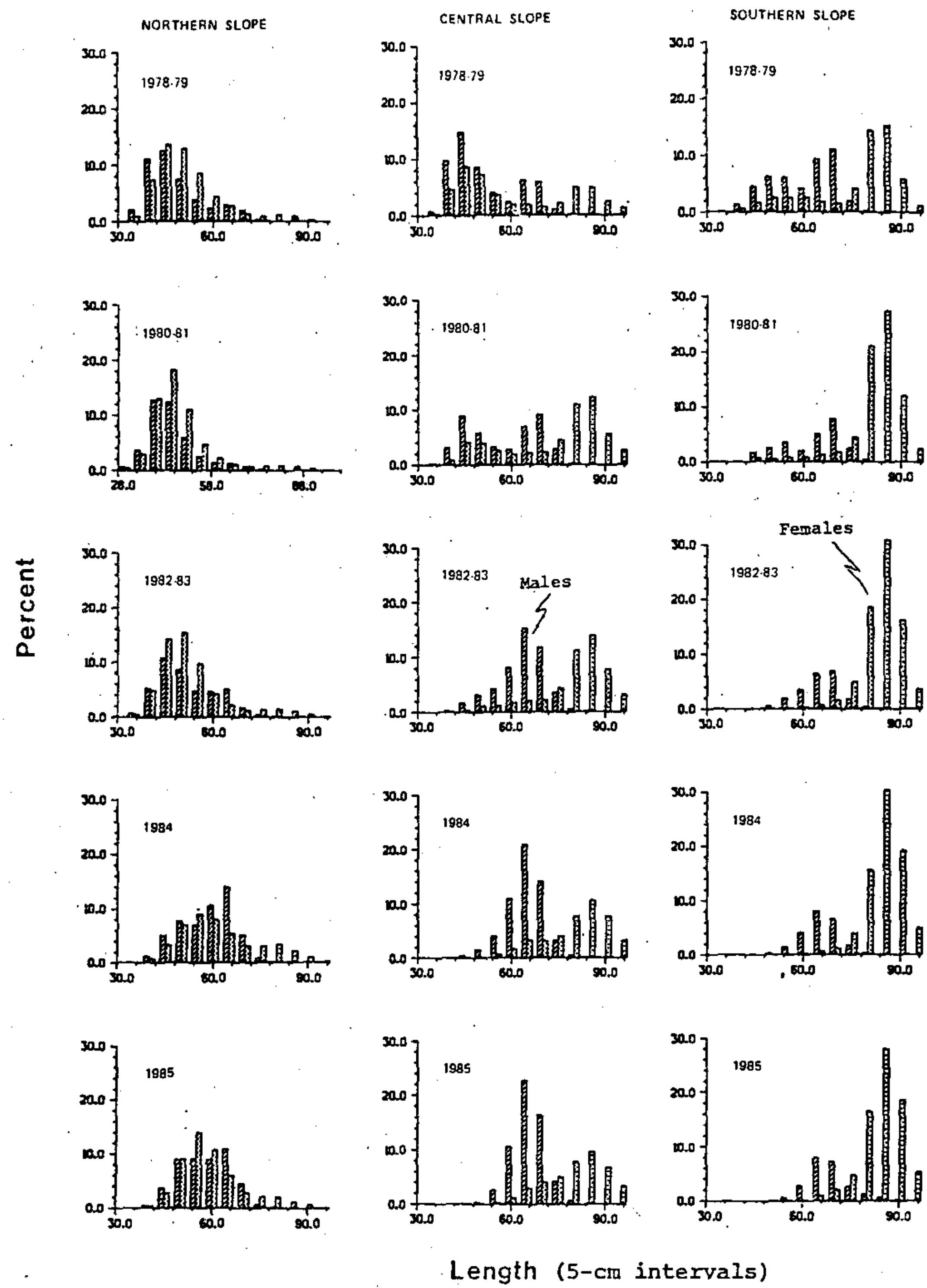

Figure 12.--Length composition by sex of Greenland halibut taken by Japanese small trawlers in the Continental Slope region of the eastern Bering Sea, 1978-85.

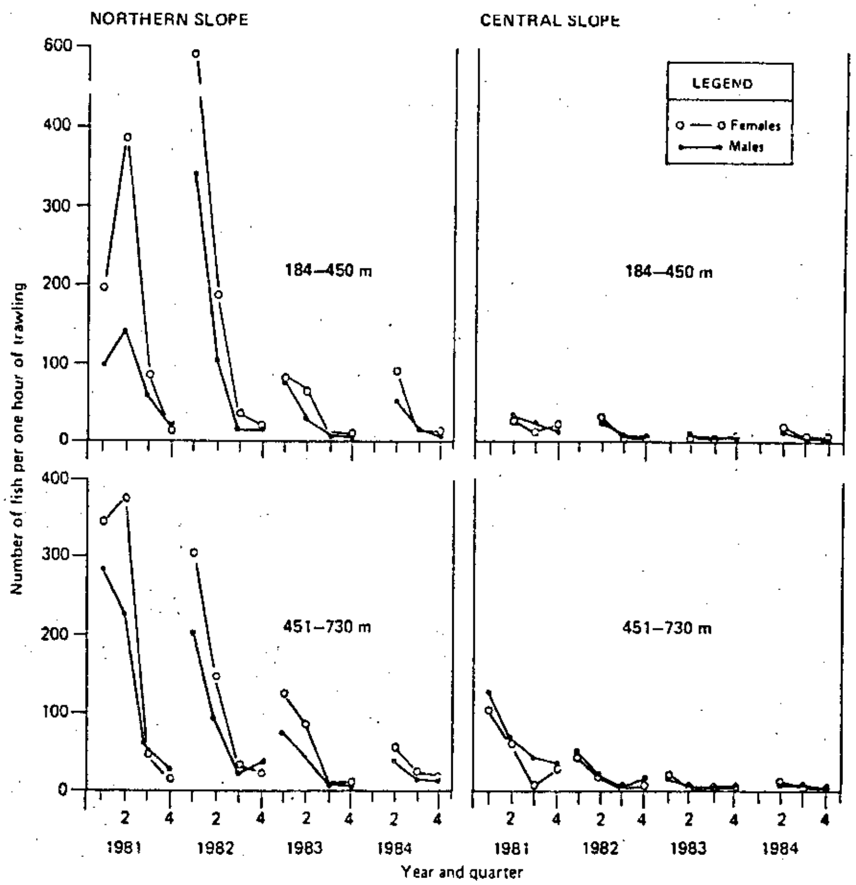

Figure 13.--Quarterly catch rates of immature Greenland halibut by Japanese small trawlers in the Continental Slope region of the eastern Bering Sea, 1978-84 (length groups: males <55 cm, females <70 cm).

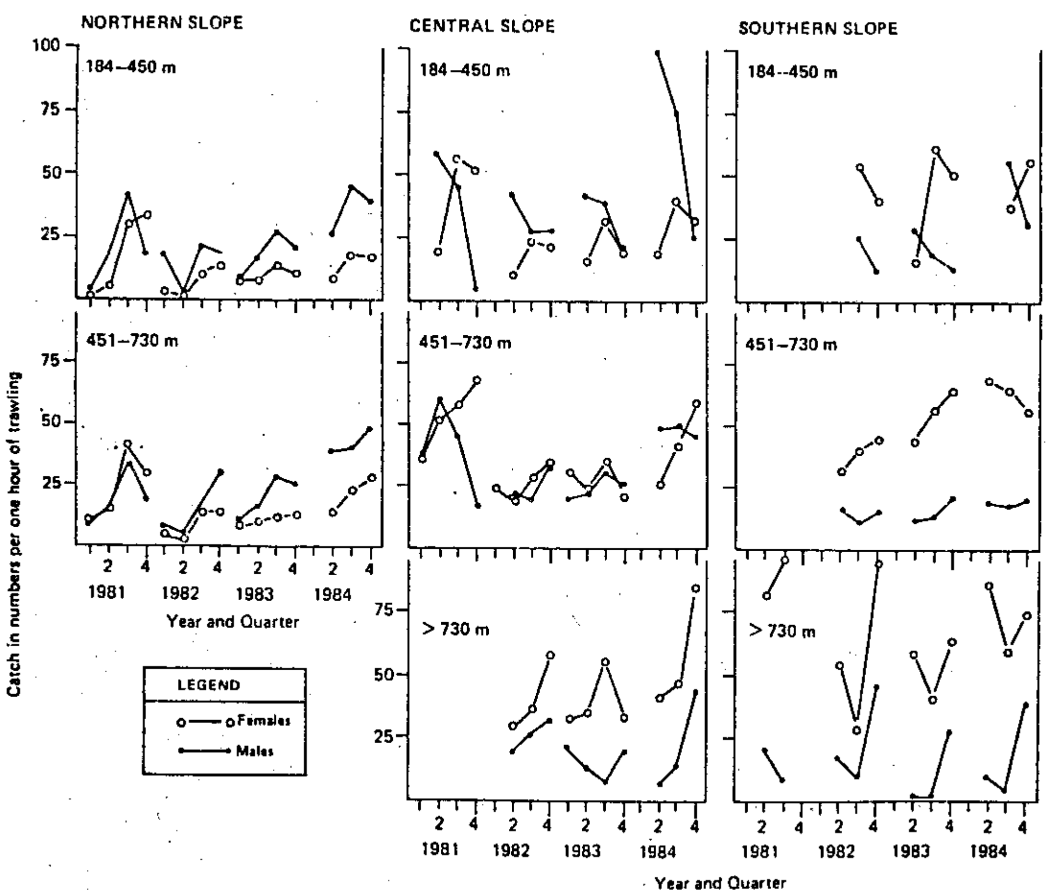

Figure 14.--Quarterly catch rates of mature Greenland halibut by Japanese small trawlers in the Continental Slope region of the eastern Bering Sea, 1981-84 (length groups: males ≥ 55 cm, females

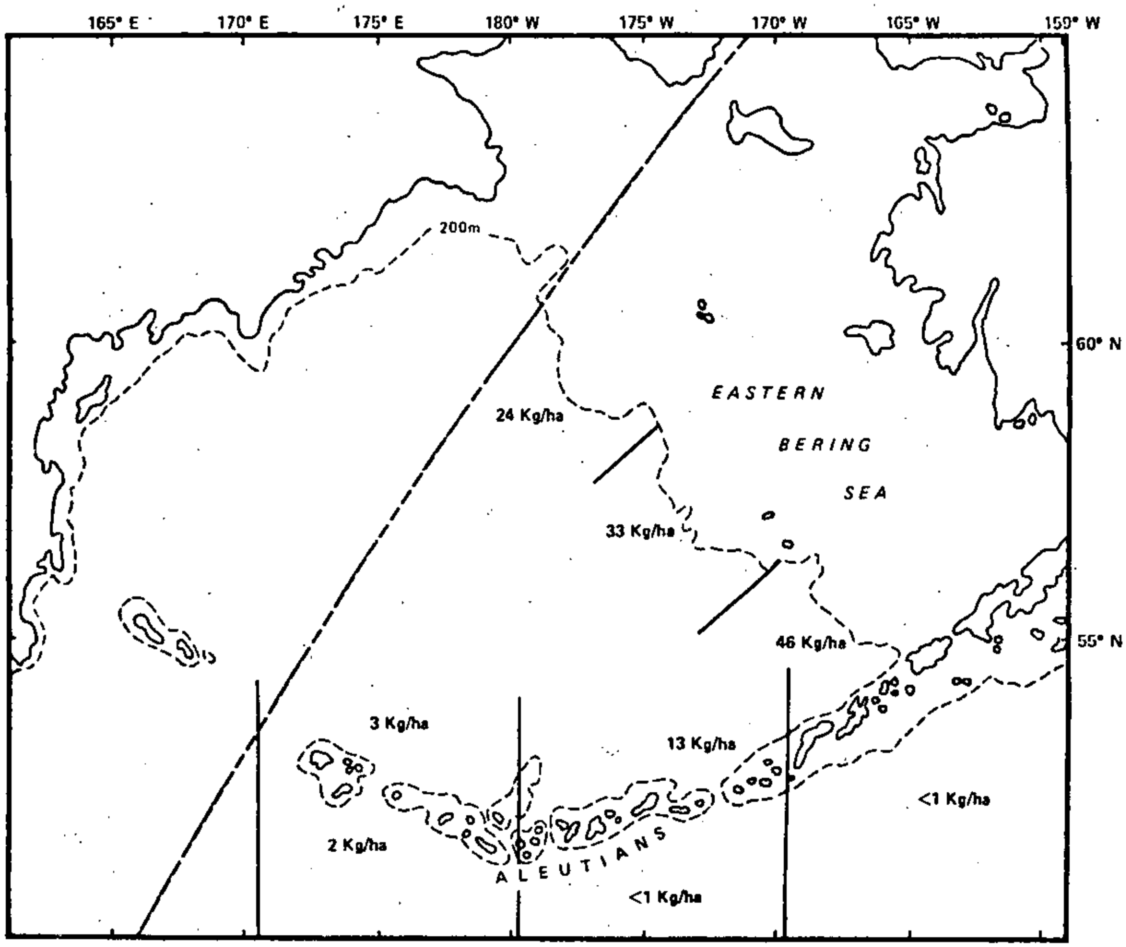

Figure 15.--Relative density distribution of Greenland halibut in the slope area of the eastern Bering Sea and Aleutian Islands as determined from U.S.-Japan cooperative trawl surveys in 1979-80.

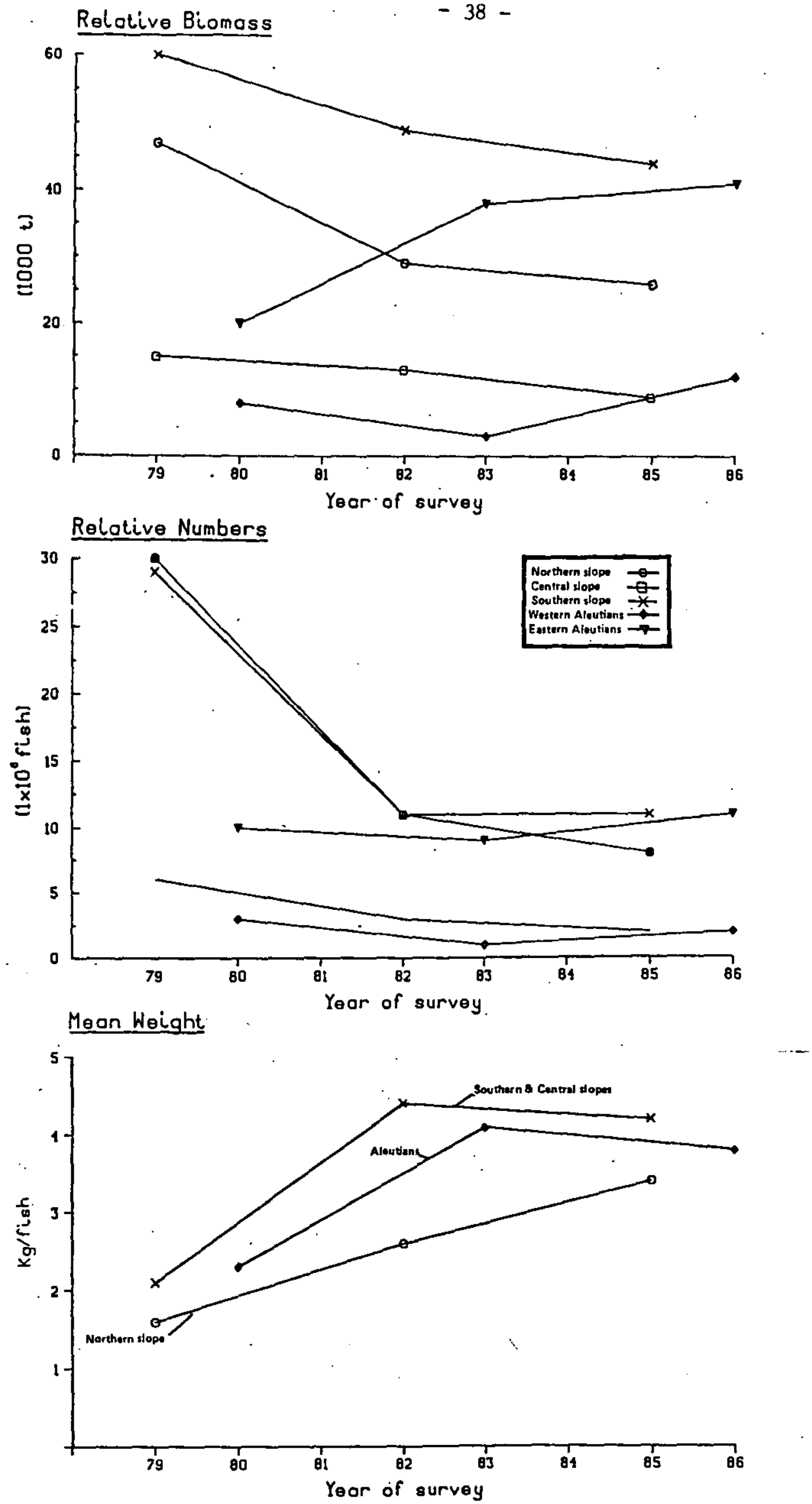

Figure 16.--Temporal changes in the relative biomass and numbers of Greenland halibut in the eastern Bering Sea and Aleutian Islands related to individual mean weights, 1978-86. Estimates are from U.S.-Japan cooperative trawl surveys.

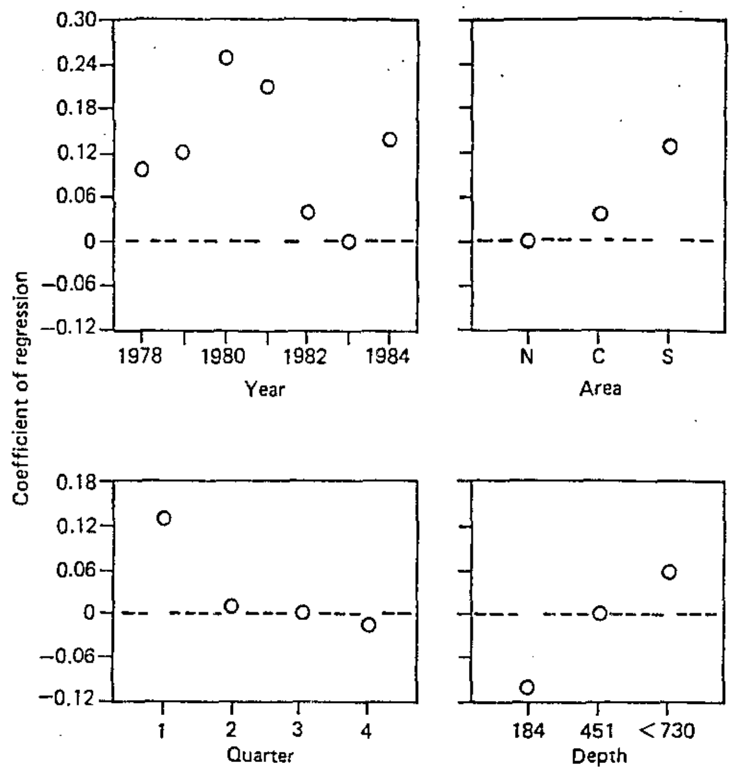

Figure 17.--Results of regression analysis of Greenland halibut CPUE showing regression coefficients by main effects (year, area, quarter, and depth).

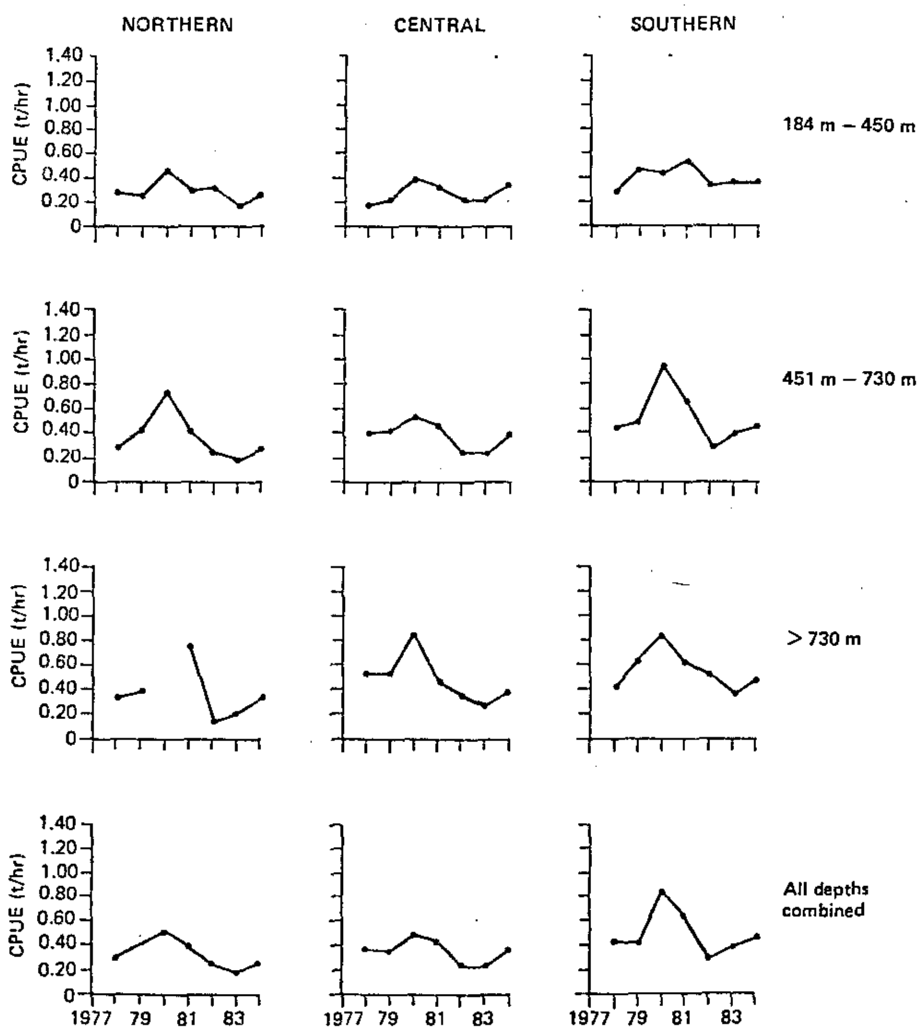

Figure 18.--Annual changes in Greenland halibut CPUE of Japanese small trawlers given by depth and area of the Continental Slope of the eastern Bering Sea, 1978-84 (estimated from NMFS observer

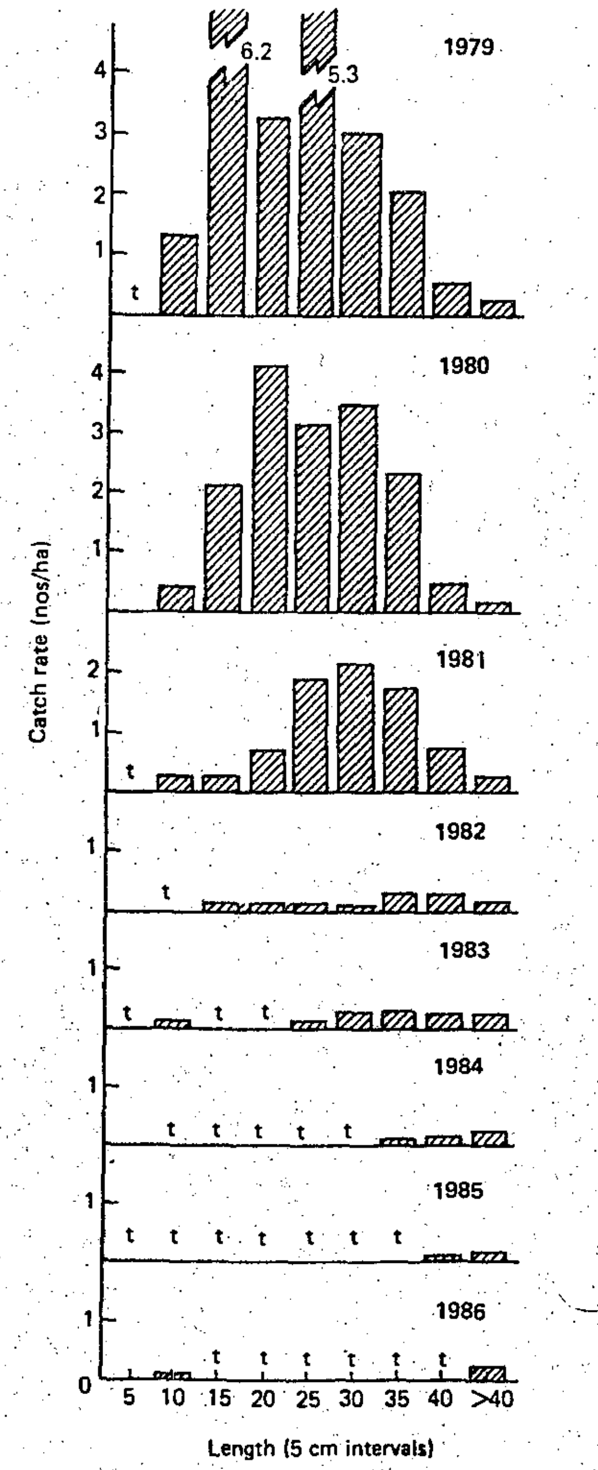

Figure 19.--Catch rate of Greenland halibut by 5-cm length groups during NWAFC annual summer bottom trawl survey in the shelf region of the eastern Bering Sea, 1979-86.

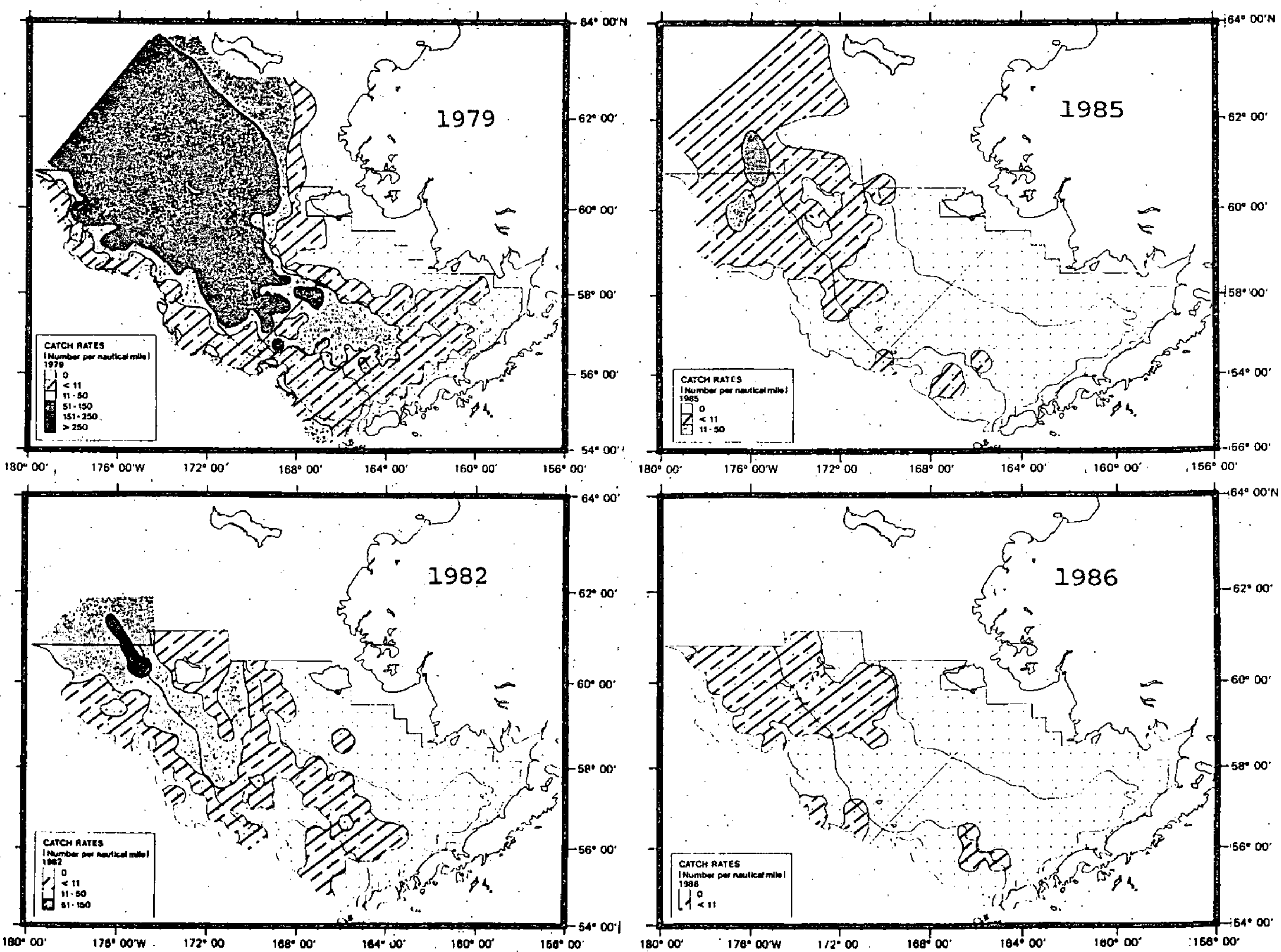

Figure 20.--Estimate of the density distribution of Greenland halibut during NWAFC summer bottom trawl surveys in the shelf region of the eastern Bering Sea in 1979, 1982, 1985, and 1986.

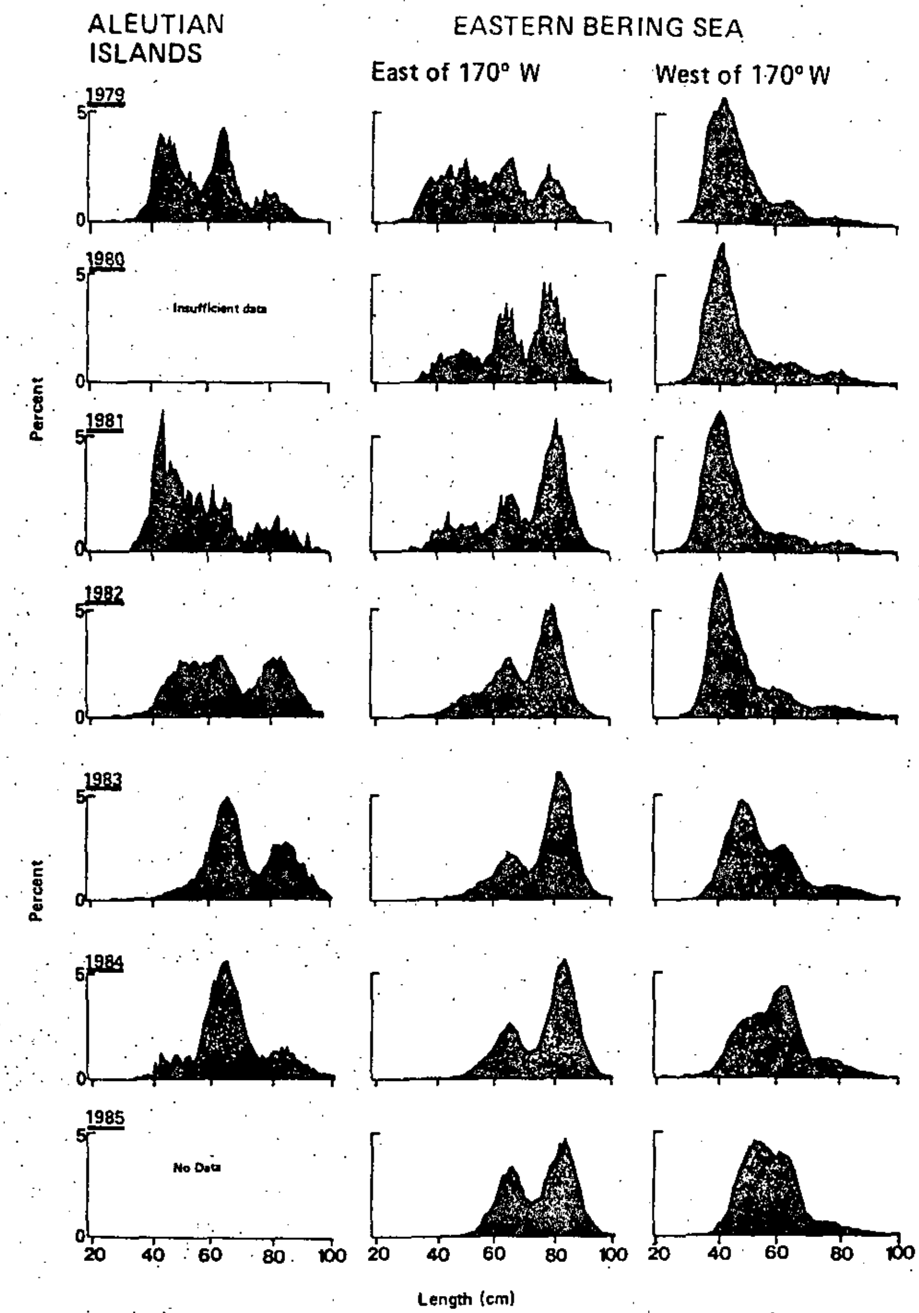

Figure 21.--Length composition of Greenland halibut taken by Japanese small trawlers in the eastern Bering Sea and Aleutians, 1978-85.

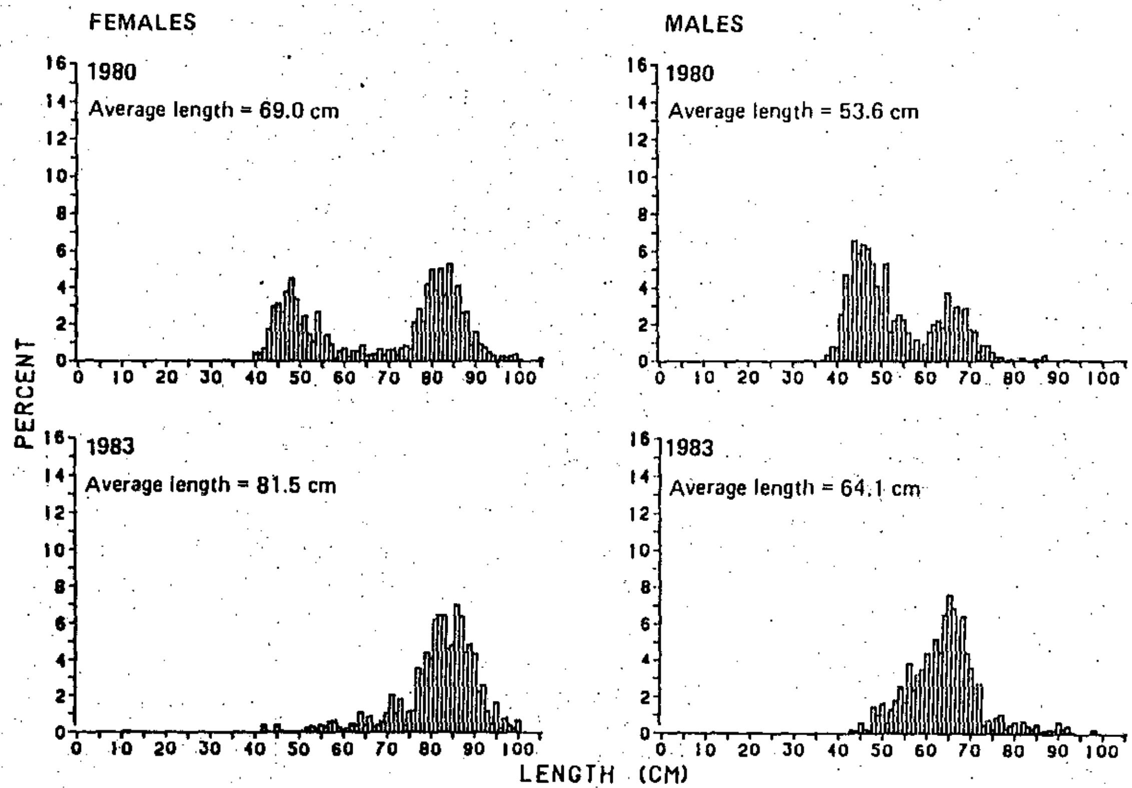

Figure 22.--Length composition of Greenland halibut as estimated from U.S.-Japan cooperative bottom trawl surveys in the Aleutian Islands in 1980, 1983.